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Wrist posture during computer mouse with and without chair armrests

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WRIST POSTURE
DURING COMPUTER MOUSE
WITH AND WITHOUT CHAIR ARMRESTS

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ABSTRACT

WRIST POSTURE DURING COMPUTER MOUSE USE
WITH AND WITHOUT CHAIR ARMRESTS

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In a laboratory-based study, 20 experienced computer operators were monitored to determine the effect of fully-adjustable chair armrests on wrist posture during computer mouse use. A mixed-factors design with two independent variables, Armrest Condition (with and without chair armrests) and Armrest Experience (armrest users and nonusers) was used. Participants performed mouse-based computer tasks for 18 minutes for each armrest condition. Data were collected for wrist posture, right upper extremity points of contact, operator technique, subjective ratings of fatigue, discomfort, and preference. Results showed that use of chair armrests generally resulted in less time in non-neutral wrist postures for extension and ulnar deviation. Overall, wrist posture and subjective ratings showed some benefit from the use of chair armrests during computer mouse use; points of contact and operator technique showed a possible increased risk. Further research studies must be completed to understand the full impact of chair armrests on the PC operator in the work environment.

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INTRODUCTION

CTDs and the Computer Operator

Upper extremity cumulative trauma disorders (CTDs) among computer users have increased significantly since the early 1980s. There has been significant growth in reported CTD cases as the popularity and demand for computers in the work setting have increased (Bureau of Labor Statistics, 1992). CTDs typically occur primarily in the neck and upper extremities including the shoulders, elbows, wrists, and hands of personal computer (PC) operators (Faucett & Rempel, 1996). Awkward postures of the upper extremity, contact pressure, as well as static muscle loading, repetition, and force have all been identified in the literature as risk factors contributing to CTDs (Armstrong, Martin, Rempel, & Johnson,1995; Berqvist, Wolgast, Nilsson, & Voss, 1995; Hunting, Laubli, & Grandjean, 1981).

The literature has suggested a link between CTDs and the computer mouse input device commonly used with computer systems (Fogelman & Brogmus, 1995). With the popularity of the graphical use interface, such as the Windows operating system and the point-and-click simplicity of input devices, use of the computer mouse by PC operators has increased dramatically. Software programs being developed require intensive mouse use. Johnson, Dropkin, Hewes and Rempel (1993) found that mouse use was significant when analyzing the percentage of time spent on the keyboard and mouse in various software applications. Sixty-five percent of the time was spent on the mouse during graphics and drawing tasks, 40% for database, and 30% for word processing tasks.

Ergonomic Risk Factors and the Computer Mouse

With this increase in mouse use, associated discomfort in the upper extremities is also being reported by PC operators (Attwood, 1986; Karlqvist, Hagberg, Koster, Wenemark, & Anell, 1996). Common CTDs related to using the computer mouse include shoulder and neck discomfort, wrist and finger tendinitis, lateral epicondilitis, and ulnar nerve compression at the wrist (Attwood, 1986; Davie, Katifi, Ridley, & Swash, 1991; Franco, Castelli, & Gatti, 1992; Norman, 1991; Pascarelli & Kella, 1993). (Note: a description of the medical terms used in this paper is provided in the Glossary.) Risk factors that contribute to these CTDs include (a) awkward postures of the shoulder, elbow, forearm, and wrist, (b) static muscle loading, (c) contact pressure at the elbow, forearm, and wrist, (d) force, and (e) repetition (Armstrong, et al., 1995; Karlqvist, Hagberg & Selin, 1994). The following sections identify the literature documenting selected CTD risk factors and how such risk factors apply to computer mouse use.

Awkward postures of the shoulder. The impact of awkward shoulder postures and their contribution to CTDs have been well documented in the literature (Berqvist et al., 1995; Sauter, Schleifer, & Knutson, 1991). Prolonged, repetitive posturing of the shoulders in flexion and elevation over a prolonged period of time can shorten the pectoral muscles, upper trapezius, scalenes, and levator scapula. This can result in postural dysfunction disturbing the anatomical relationship of the involved structures of the shoulder complex. Clinical diagnoses related to postural dysfunction include thoracic outlet syndrome, nerve irritation, myofascial trigger points, and shoulder impingement (Keller, Corbett, & Nichols, 1998). Ergonomic recommendations for the shoulder during computer mouse use state that shoulder flexion, rotation, and abduction be as low as possible. PC operators should work with the upper extremities close to the body to minimize risk (Chaffin & Andersson, 1991).

Awkward postures of the shoulder have been identified during computer mouse use. Karlqvist et al. (1994) compared mouse operators to nonmouse operators during a word processing task. It was found that mouse operators worked in more extreme positions at the shoulder; shoulder range of mouse operators measured from 5° external rotation to 65° external rotation as compared to 65° of internal rotation to 10° of external rotation for nonmouse operators. The shoulder worked 81% of the time in external rotation > 30°. It has also been observed that when a forward, lateral reach is required to maneuver the mouse, PC operators typically posture the right arm in the biomechanical pattern of shoulder flexion, abduction, and internal rotation, particularly when the operator is sitting too far from the work surface. In summary, computer mouse use with the standard keyboard mouse setup requires static and awkward postures of the shoulder. This extended reach for the computer mouse, particularly for an increased period of time, can contribute to CTDs of the shoulder/neck region (Karlqvist et al., 1996).

Awkward postures of the elbow. Awkward postures of the elbow have been identified as a risk factor in the ergonomics literature. Common diagnoses related to non-neutral postures of the elbow include cubital tunnel syndrome and lateral epicondilitis. Neutral range for the elbow in the ergonomics literature is 90° elbow flexion. Research has shown that tasks requiring forearm rotation and push-pull tasks have greater force when the elbow is flexed to 90° (Brunnstom, 1992; Chaffin & Andersson, 1991). Elbow flexion > 90° can result in cubital tunnel syndrome due to increased tension at the fibrous arch of the flexor carpi ulnaris (Pecina, Krmpotic-Nemanic, & Markiewitz, 1993).

There is a controversy among ergonomists regarding the optimal elbow angle while using the keyboard and mouse. Ergonomists typically recommend 90° elbow flexion (or 90° extension) with the shoulders relaxed to the side of the body for keyboarding; however, others have recommended greater and lesser elbow flexion angles (Carter & Banister, 1994). No specific recommendations have been found for optimal elbow angle while using the computer mouse. It is recommended in the literature that the computer mouse be located near elbow height to minimize wrist extension and flexion (Armstrong et al., 1995; Damann & Kroemer, 1995); however, this recommendation does not specifically identify preferred elbow angle.

Working with the elbow in awkward postures is common during computer mouse use with the right hand. PC operators, using the computer mouse, typically work with the shoulder flexed and the elbow extended > 90° (Karlqvist et al., 1994). Many factors can contribute to the right elbow working in a position > 90° extension. With right mouse use, the added width of the keyboard with the number keypad and arrow keys results in greater reach for the computer mouse with an extended elbow (Paul, Lueder, Selner, & Limaye, 1996). PC operators with narrow shoulder breadth are required to work with greater shoulder flexion, shoulder abduction, and the elbow in an overextended position (Karlqvist, et al. 1998). Short forearm length and sitting too far from the work surface can also contribute to overreaching for the computer mouse.

Awkward postures of the wrist. Awkward wrist postures or non-neutral postures of the wrist have been identified as a risk factor in the literature. There are four motions of the wrist including (a) extension, (b) flexion, (c) radial deviation, and (d) ulnar deviation. Refer to Figure 1 for joint posture definitions and range of motion (ROM) of the wrist. Optimal range of motion for the wrist during hand function is 10° extension. This is based on determining the resting length of the muscles acting on the wrist. At resting length, muscles can exert a maximum contraction with the least amount of force compared to other ranges (Brand & Hollister, 1993).

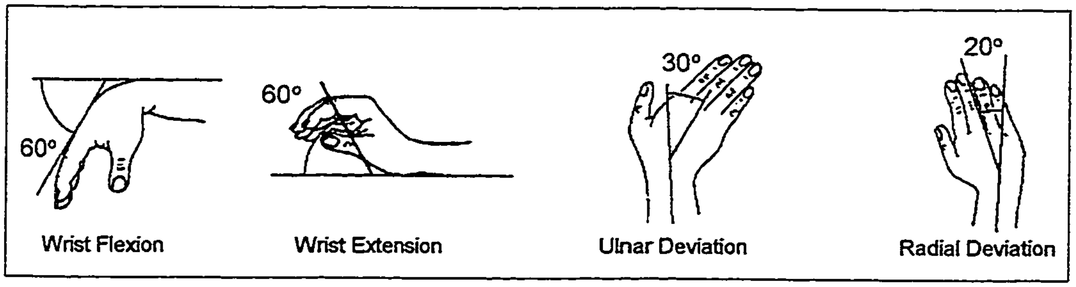

Figure 1. Joint posture definitions and available range of motion of the wrist. From Swanson, A. B., Swanson, G. G. & Goran-Hagert, C. (1990). Evaluation of impairment of hand function. In J. M. Hunter, L. H. Schneider, E. J. Mackin, & A. D. Callahan (Eds.). Rehabilitation of the hand: Surgery and therapy (pp. 109-138). St Louis: C.V. Mosby.

Armstrong & Chaffin (1979) identified the biomechanical effect of non-neutral wrist postures and how they contribute to CTDs such as carpal tunnel syndrome (CTS) and tenosynovitis of the flexor tendons. Biomechanical stress to the tendons and decreased carpal tunnel space can occur when the wrist is flexed, extended, or deviated greater than neutral. Tendons become displaced within the carpal canal, resulting in higher forces on the tendons. With repetition, this can result in tendon swelling and/or tendinitis. Decreased carpal tunnel space and increased intracarpal pressure can also occur with non-neutral wrist postures, which can result in carpal tunnel syndrome over time. When intracarpal pressure increases to > 30 mm Hg, stability of the median nerve can be compromised (Lundborg, et al. 1982). It has been documented in the keyboard literature that the lowest carpal tunnel pressure occurs with wrist extension between 0° and 15° (Rempel & Horie, 1994). As the wrist extends, carpal tunnel pressure increases. It has been recommended that the wrist be positioned between 0° and 15° wrist extension (neutral range of the wrist) during typing tasks to minimize carpal tunnel pressure. Typing positions in more extreme postures (> 30°) should be avoided (Bach, Honan & Rempel, 1997).

There is no significant increase in carpal tunnel pressures with deviation except in extreme ranges of ulnar deviation and radial deviation (> 15°). However, the negative biomechanical effect of repetitive strain on the tendons within the carpal canal has been documented (Armstrong & Chaffin, 1979). Repetitive ulnar deviation > 15° to 20° can increase pain symptoms in computer operators (Hunting, et al., 1981). Radial deviation >15 ° has been found to increase carpal tunnel pressures during keyboard use and should be avoided (Bach et al., 1997).

Awkward wrist postures have been identified during computer mouse use. In the study by Karlqvist et al. (1994) that examined shoulder postures with and without mouse use, wrist deviation was also measured. It was found that mouse operators had a tendency to work with the wrist in ulnar deviation with more extreme positions (5° radial deviation and 60° ulnar deviation) compared to nonmouse operators (-35° radial deviation and 35° ulnar deviation). Compared to PC operators using the keyboard only, mouse operators spent a significantly greater time in awkward postures > 15° of ulnar deviation. The research confirmed that PC operators using the mouse spend greater amounts of time in awkward postures of wrist ulnar deviation than PC operators who use the keyboard only; 34% of the time was spent in 15° to 30° ulnar deviation versus 2% for nonmouse operators, and 30% versus 0% of the time was spent in ulnar deviation > 30°. Wrist extension was not measured in this study.

Wrist extension has also been found to be more prevalent during computer mouse use. Many factors affect on the degree of wrist extension. These include (a) the design of the computer mouse, (b) hand positioning and method of manipulation by the PC operator, (c) use of accessories such as wrist supports, and (d) elbow height in relation to the work surface or computer mouse height (Armstrong et al., 1995). Damann & Kroemer (1995) studied the relationship of seated elbow height and its effect on wrist extension and flexion, as well as the effect of the wrist support when used with the computer mouse. Work surface heights that were 80%, 100%, 120%, and 140% of seated elbow height were evaluated. It was recommended that work surface height be located between 100% and 120% of seated elbow height to minimize wrist extension; use of a wrist support also decreased wrist extension. Shoulder and elbow range of motion during computer mouse use were not evaluated.

Static muscle loading of the upper extremity. Static muscle loading is a prolonged muscle contraction that remains in a heightened state of tension. Static muscle loading greater than 5% to 8% of the maximum voluntary contraction (MVC) can contribute to CTDs (Grandjean, 1987; Sjoogard, Savard, & Joel, 1988). This type of contraction will reduce blood flow and oxygen to the muscle, resulting in fatigue and muscle pain (Chaffin & Andersson, 1991; Grandjean, 1987). Static muscle loading can occur when working in neutral postures. If the static muscle load is greater than 5% when working in neutral range, the negative effects of statically loading the muscle for a prolonged period of time can contribute to CTDs. Awkward postures can increase the degree of static muscle loading. This can result in greater risk due to a combination of static muscle loading and awkward wrist postures.

Computer mouse use requires static muscle loading or stabilization of the upper body to allow for controlled cursor movement. Stabilization is provided by (a) muscle contraction or static muscle loading, (b) external support (i.e., chair armrests, worksurface), or (c) a combination of both muscle contraction and external support. Whether static muscle loading exceeds the recommended 5% to 8% MVC to stabilize the arm in position during computer mouse use is dependent on many factors related to the workstation environment and physical characteristics of the PC operator. These include (a) workstation setup (work surface height, keyboard/mouse location), (b) operator technique including the operator's posture and distance from the keyboard/pointing device, (c) use of external support, (d) individual muscle strength (MVC) of the PC operator, and (e) an operator's tendency to hold increased muscle tension during computer tasks (Erdelyi, Sihvonen, Helin, & Hanninen, 1988).

Contact pressure. External pressure or contact pressure to underlying nerves and soft tissues of the upper extremity is a common CTD risk factor. External pressure to nerves can result in ischemia and neurovascular changes that affect sensory and motor functions of the upper extremities. Common diagnoses of the upper extremities related to external pressure on the nerves include (a) cubital tunnel syndrome (compression of the ulnar nerve at the elbow), (b) ulnar tunnel syndrome (compression of the ulnar nerve at the wrist), and (c) carpal tunnel syndrome (compression of the median nerve at the wrist).

There are many factors that determine the amount of contact pressure and its effect on underlying nerves and soft tissues. These include the (a) magnitude of the force, (b) duration of the force, (c) location of the force applied (how superficial the nerve is to the skin), and (d) the size and distribution of the contact area. Pressure will increase as size of the contact area decreases (Armstrong et al., 1995; Szabo, 1989). Tolerance of the median nerve to graded compression (magnitude of the force) at the carpal tunnel area has been studied in the medical literature. As mentioned previously, Lundborg et al. (1982) found that 30 mm Hg of pressure resulted in mild sensory changes of the hand. A complete local conduction block was noted at 40 to 50 mm Hg over a prolonged period of time.

Contact pressure has not been studied during computer mouse use. The ergonomics literature identifies areas that commonly have contact with the mouse pad surface (Armstrong et al., 1995); however, no field studies have documented the location of contact pressure. The following section identifies the different areas of contact pressure at the upper extremity that can occur with computer mouse use including contact pressure at the elbow, forearm, and wrist.

Contact pressure at the elbow can occur during computer mouse use when the elbow is placed on surfaces such as the hard edges of desks or chair armrests. PC operators can also *pivot at the elbow*, a movement resulting from shoulder rotation, when maneuvering the computer mouse. This can result in increased pressure at the ulnar nerve. The ulnar nerve at the elbow lies between the olecranon process and medial epicondyle. If external pressure is applied to these bony prominences simultaneously, particularly with the forearm pronated, compression of the ulnar nerve can occur (Mosely, Kalafut, Levinson & Mokris, 1991; Reddy, 1986).

Contact pressure occurs at the proximal and middle portions of the forearm during computer mouse use when utilizing upper extremity support such as the work surface or chair armrest. Contact pressure at the distal portion of the forearm is more common during computer mouse work as PC operators use this portion of the forearm as an area of support or contact on the mouse pad. Contact pressure at the proximal and middle portions of the volar forearm has not been identified in the literature as a risk factor. Currently, it is not clear whether contact pressure in the forearm can cause sufficient compression to affect the function of the underlying median and ulnar nerves to be implicated as a CTD risk factor during computer mouse use.

Contact pressure at the volar wrist is common during mouse use. PC operators typically rest the volar wrist on the mouse pad surface. Resting the wrist on the mouse pad surface assists in supporting the upper extremity and stabilizing the wrist to improve manipulation of the computer mouse. Contact pressure at the volar wrist or carpal canal during computer mouse use has not been studied in the ergonomics literature. Rempel &

Horie (1994) discussed the effect of external contact pressure on the volar wrist in their study on carpal tunnel pressures while keyboarding with and without a wrist support. Carpal tunnel pressures significantly increased when external pressure was applied to the volar wrist/palm area when resting on a wrist support and a desk surface. When pressures were compared to *floating* over the keyboard with no contact on any surface and resting the volar wrist on the work surface, there was a significant decrease in carpal tunnel pressure with the floating technique. These results from keyboard research can be applied to computer mouse use. It can be assumed that contact pressure at the volar wrist could also increase carpal tunnel pressure while using the computer mouse, although contact pressure during this task has not been specifically addressed in the ergonomics literature.

The ulnar nerve can also be compressed as it crosses the volar wrist due to the mouse operator's tendency to rest on the ulnar border of the hand when the forearm is held in less than full range of pronation (Franco et al., 1992; Ranney, 1993). It was reported that with increased repetition and duration over time, this posture can result in ulnar tunnel syndrome (Franco et al., 1992).

In summary, contact pressure during computer mouse use has not been thoroughly studied in the literature. To understand the effects on the nerve and underlying soft tissues, research must address the factors contributing to contact pressure during computer mouse use including (a) magnitude of the force applied, (b) duration of the force, (c) location of the force or point of arm contact on the surface, (d) size and that the distribution of the contact area, and (e) density of the surface (i.e., work surface, arm rest

PC operator is using as a support).

<u>Operator technique.</u> The PC operator's technique in manipulating the computer mouse and its contributions to CTDs has not been well documented in the literature. The importance of analyzing operator style or technique and its contributions to CTDs has been referenced in the keyboard literature (Pascarelli & Kella,1993; Paul, Menon, & Nair, 1995). Analyzing the technique of 53 keyboard operators, Pascarelli and Kella (1993) identified CTD risk factors related to operator technique during keyboard use. Contributing risk factors included (a) using greater force than necessary to activate the keys, (b) leaning on the keyboard surface or wrist rest to activate the keys, resulting in greater demand on the wrist and fingers; and (c) leaning on one side while keying. Analysis of mouse technique in this study was limited to two PC operators, and gripping the mouse too tightly was the only risk factor identified.

Although research on operator technique for using the mouse is limited, application of risk factors associated with the PC operator's style of keyboard technique can be applied to using the computer mouse. There are multiple factors that can be used to categorize operator technique when using the computer mouse. These include:

1. Identification of joint movement of the upper extremity used to maneuver the computer mouse such as movement through the shoulder, elbow, and/or wrist.
2. Hand positioning or grip on the mouse with identification of the method of finger manipulation (i.e., finger motion used to maneuver the mouse).
3. Force applied to hold the mouse and activate the mouse buttons.
4. Body posture during computer mouse use.

It is unclear how the PC operator is actually maneuvering the mouse in the workplace. There are no field studies available that document the PC operator's technique for maneuvering the mouse during various mouse-based tasks. Many external factors can have an effect on operator technique such as workstation setup, including type of work surface, keyboard and pointing device, and type of upper extremity support being used. Ergonomic recommendations have been made on how PC operators should maneuver the mouse and what postures to use or avoid based on ergonomic principles. Following are the recommendations that have been made in the ergonomics literature as related to upper extremity motion. No reference has been made to force or speed.

1. Minimize wrist deviation by using the entire forearm. It must be considered that an energy penalty can result when using the added mass of the entire forearm (Armstrong et al., 1995).
2. Minimize wrist flexion and extension by locating the mouse near elbow height (Armstrong et al., 1995) or at least 100% to 120% of seated elbow height. Use of a wrist support results in more neutral wrist posture (Damann & Kroemer, 1995).
3. The entire arm and shoulder should be used to move the mouse. Do not use the wrist only (Pascarelli & Quilter, 1994).
4. Locate the mouse to avoid contact between the volar wrist and mousing surface (Armstrong et al., 1995).

Operator technique for maneuvering the computer mouse is a subject of debate among ergonomists. Some ergonomists state that wrist motions should be used for more detailed mouse work when the target distance is minimal and precision is required, while gross movements, such as moving the mouse across the screen to close a window, should be done by the stronger muscles of the shoulder with the wrist in neutral posture. Other ergonomists recommend using the entire arm for all mouse-based tasks in order to transfer the workload to the stronger shoulder muscles while resting the hand on the mouse and avoiding contact at the volar wrist (S. Wright, personal communication, November 4, 1997). There have been no studies that identify what technique is currently being used by PC operators to maneuver the computer mouse.

In summary, computer mouse use has inherent risk factors that can contribute to CTDs. The interaction of these risk factors with the risk factors demanded by the work task, such as increased repetition and duration, can heighten the effects of the CTD risk factors. In an attempt to minimize the risk factors associated with mouse use, ergonomists working with PC operators are attempting to address the inherent risk factors in computer mouse use by (a) determining optimal work surface heights, (b) minimizing contact pressure, (c) reducing static muscle loading, and (d) minimizing non-neutral postures of the upper extremities. Training PC operators how to use the computer mouse to minimize risk factors is also being addressed, although there is controversy on what technique should be used (i.e., movement from the shoulder only or a combination of both the shoulder and hand). Other recommendations being made by some ergonomists, employers, and PC operators to minimize CTD risk factors include providing upper extremity support during PC tasks. By providing support, it is believed that CTD risk factors will be reduced. The following section identifies products that are available for upper extremity support to the PC operator during computer mouse use.

Ergonomic Aids/Products to Minimize CTD Risk Factors During Mouse Use

Ergonomic products such as moving forearm supports, static forearm support boards, and mouse wrist supports are being used by PC operators (Appendix A). Other simple methods of upper extremity support includes using the actual keyboard and mouse work surface and chair armrests. With the popularity of ergonomic chairs that provide adjustable armrests and the tendency for PC operators to use support whenever it is available, the chair armrest has become a common means of upper extremity support during computer mouse use.

Chair Armrests - History and Purpose

Armrest design has evolved in past years as ergonomic chair design has become more sophisticated for the office worker. In the 1970s, the typical office chair had either no chair armrest or fixed arms at one height. Armrests were used for assistance in getting in and out of chairs and as arm support during sedentary tasks. The subsequent phase of chair armrest design allowed for increased adjustability by allowing height adjustment. Realizing the need to *fit the worker* and to accommodate for the change in work tasks (i.e., addition of the computer mouse input device) (Paul, et al., 1996), chair manufacturers continued to enhance the design of ergonomic chair armrests with greater adjustability. Multiple chair armrest designs are now available to the computer operator. Features that have been added to some fully-adjustable models of chair armrests include (a) horizontal adjustment, (b) angle of inclination, (c) distance between armrests, and (d) rotation (Paul et al., 1996). An example of the type of armrests that are now available to the PC operator by Office Master, a large manufacturer of ergonomic chairs, includes the rotation (Paul et al., 1996). An example of the type of armrests that are now available to the PC operator by Office Master, a large manufacturer of ergonomic chairs, includes the Maximum Motion Armrest I, Maximum Motion Armrest II, 3-way Adjustable Armrests and Adjustable T Armrests (see Figure 2). The following section will discuss the guidelines available for the PC operator on the use of chair armrests during mouse use.

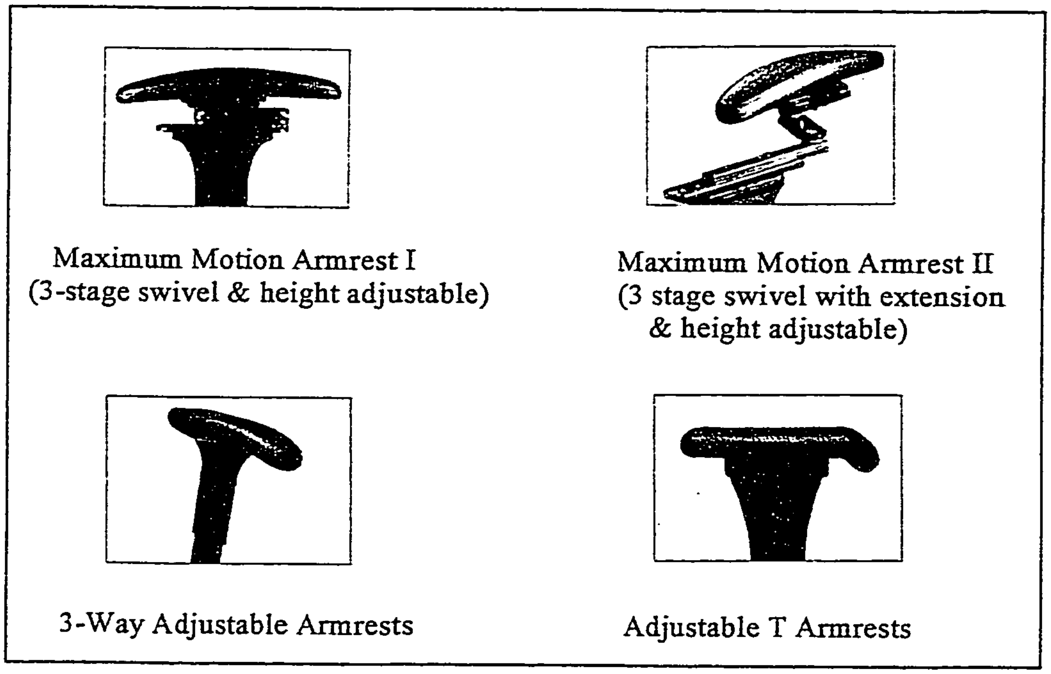

Figure 2. Illustration of adjustable chair armrests by Office Master.

Guidelines for Chair Armrest Use During Computer Mouse Use

Guidelines for the PC operator on the use of chair armrests during computer mouse use are limited. Currently, there are no specific guidelines in the ANSI standards (1988) on whether chair armrests should be used when using the computer mouse. The guidelines include limited recommendations on chair armrest specifications only (Appendix B). Publications for the PC operator make limited recommendations on how vague, stating that chair armrests should be short and padded and should not be used while typing. Don Sellars, the author of *Zap! How Your Computer Can Hurt You and What You Can Do About It* (1994), states that experts are undecided whether armrests should be used during typing with no reference to the computer mouse.

Manufacturers of ergonomic chairs make claims regarding the use of chair armrests and arm support during computer mouse use. BodyBilt Seating, Inc., a chair manufacturer, claimed that proper adjustment of chair armrests can decrease the risk of carpal tunnel syndrome by correctly aligning the hand, wrist, and forearm along the same plane (Appendix C). This would allow for working in neutral postures. AliMed, Inc. (1998), a vendor of ergonomic products, claims that arm supports can reduce or eliminate pressure on the carpal tunnel by allowing the wrist to float above the work surface. Whether chair armrests allow for proper alignment of the forearm and hand on the same plane or reduce the pressure on the carpal tunnel area (volar wrist) during computer mouse use is unknown at this time. With this lack of general guidelines in the commercial and ergonomics literature for PC operators, researchers are beginning to study the use of chair armrests during computer mouse use. This research is discussed in the following section.

<u>Research - Chair Armrests for the PC Operator during Mouse Use</u>

Research on chair armrests for the PC operator has focused on the effect of chair armrests on the level of muscle activity and fatigue of the shoulder and wrist. A study by Paul et al. (1996) compared 11 computer operators using (a) height and rotation-adjustable chair armrests (fully adjustable), (b) height-only adjustable chair armrests and

(c) no chair armrests when operating the keyboard and computer mouse. Muscle fatigue in the shoulder and forearm were measured during 90 minutes of continuous mouse use in a graphics task and 60 minutes of a keyboard task. Perceived discomfort and preference between the three armrest conditions were also evaluated. Electromyography (EMG) data showed that when using the computer mouse, a significantly lower level of muscle fatigue at the shoulder (trapezius) and forearm flexors was measured with fully-adjustable chair armrests as compared to no chair armrests or height-only adjustable armrests. Perceived discomfort between the armrest conditions was not significantly different. Subjects preferred to use no chair armrests or the height- and rotation-adjustable armrests as compared to height-only adjustable armrests during mouse use due to the poor fit and interference of the height-only adjustable armrests. This study supports the use of arm support during mouse use to minimize shoulder and forearm muscle fatigue. More importantly, it shows that proper fit of the arm support during a computer mouse task is a critical factor. The greater adjustability of the height- and rotation-adjustable armrests (fully adjustable) allows the PC operator to achieve the proper fit which results in less muscle fatigue of the shoulder and forearm.

Wells, Lee, & Bao (1997) also studied the use of arm support during mouse use. Four types of upper extremity support conditions were evaluated during mouse use. These included (a) elbow support with a chair armrest, (b) forearm support on the work surface, (c) volar wrist support on the work surface, and (d) no arm support. Static muscle loading of the shoulder muscles (trapezius, infraspinatus), forearm muscles (flexor digitorum superficialis, first dorsal interosseous, wrist and finger extensors, extensor carpi ulnaris, pronator teres), and body discomfort were evaluated.

EMG data showed that elbow support resulted in significantly lower level of static muscle loading for the shoulder. Static muscle loading of the forearm muscles was comparable with the lowest level of static muscle loading for the forearm support. The elbow support condition resulted in the least amount of body discomfort during the testing. It was concluded that elbow support on a chair armrest and forearm support on a table were superior when measuring levels of muscle activity. Subjects preferred the elbow support or supporting their wrist on the mouse pad surface as compared to using no armrest or resting their forearm on the table. Wrist posture was evaluated; however, to date, there has been no publication of the results.

Attwood (1986) studied the individual workstation setups and discomfort levels of CADD operators, word processors, and board draftspersons. It was found that word processors and CADD operators had increased reports of pain in the right arm and neck due to intensive mouse use. Although this research study did not specifically evaluate the effect of chair armrests, observations on the use of chair armrests in the work environment were reported. Typical workstation setups included the mouse positioned too far forward and to the right, resulting in overreaching. CADD operators did have chair armrests; however, they were not fully adjustable, with no rotation or horizontal adjustments. The chair armrests also lacked ease of adjustment for armrest height. Also noted while observing this group of mouse-intensive CADD operators was that the armrests or work surface was typically not used by the operators. However, when the chair armrests were used, they interfered with fluid movement of the arm. It was also noted that when the armrests or support from the work surface was used at the level of the mouse, no discomfort was reported.

In summary, this study begins to document the use of chair armrests with intensive mouse users. The chair armrests lacked the adjustability that is currently available on ergonomic chairs (i.e., rotation and horizontal adjustments), which had an effect on the amount of arm surface that was fully supported; however, this partial arm support decreased the reports of discomfort. Interference with fluid movement of the arm was identified and can be considered to be a limiting factor with chair armrests.

Karlqvist et al. (1998) studied the effect of six locations of the computer mouse on muscle activity of the right and left trapezius, right deltoid, and right extensor digitorum. Joint postures of the right extremity were also measured. Twenty computer operators were asked to complete a 2-minute text-editing task for each mouse location. Although this study did not focus on the use of chair armrests during computer mouse use, participants had the option of using (a) no support, (b) work surface support, or (c) support from the chair armrest. The data related to arm support show that the majority of participants used the work surface or armrest as a support during computer mouse use. When using the support, 32 out of the 40 working sessions showed the lowest percentage of MVC for the participant's right trapezius muscle. It was also found that trapezius muscle activity was lower for participants who placed the work surface less than .03 m above elbow height. This confirms previous research studies' findings that arm support does decrease muscle activity during computer mouse use.

The general benefit of chair armrests has also been documented in the literature for the PC operator without specific reference to mouse use. Chair armrests can help users change positions in their chairs and assist with getting in and out of the office chairs (Lueder, 1986; Zacharkow, 1988). Research has shown that if chair armrests are properly adjusted, they can reduce the amount of body weight in the seat by supporting the weight of the arm. This results in decreased lumbar spine pressure and less tendency toward a slumped posture, which encourages more support of the upper trunk by the backrest (Nakaseko, Grandjean, Hunting, & Gierer, 1985). Occhipinti, Colombini, Frigo, Pedotti & Grieco (1985) also confirmed these findings. Their study showed that arm support reduced compressive stresses in the discs of the lumbar spine by as much as 30%.

Disadvantages of Chair Armrests for the PC Operator

Disadvantages of chair armrests during computer mouse use have not yet been identified in the research findings; however, strong opinions exist among ergonomists about their potential risk (E. K Peper, personal communication, December 18, 1997). Concerns have been raised that constrained upper extremity postures, increased static muscle loading of the shoulder and back, and contact pressure at the elbow and forearm can increase CTD risk factors while using an armrest during computer mouse use. Some ergonomists are also concerned that stabilizing the arm on an armrest can limit shoulder motion and increase non-neutral wrist postures. Others debate that if PC operators do not support the arm on the chair armrest, they will support the arm on the work surface, at the volar wrist. This could also result in increased non-neutral wrist postures and restricted shoulder motion, similar to the effect of stabilizing at the forearm. It could also pose greater risk since the volar wrist would support the weight of the arm, increasing pressure at the carpal tunnel area. Some of these concerns have not yet been addressed in the ergonomics research literature.

Other concerns have been raised regarding the effect of improper positioning of chair armrests during keyboard and mouse use. If armrests are set too far apart, increased shoulder abduction can occur; if armrests are too close together, constrained postures with shoulders adducted can result. Compression at the elbow region where the ulnar nerve is most susceptible to compression (cubital tunnel) can also occur if the armrests are set too close or not angled correctly to support the entire forearm area during keyboard or mouse use. If armrests are set too high, increased shoulder elevation can occur. If armrests are set too low, lateral trunk flexion and/or shoulder depression has been observed. Leaning on chair armrests can also result in forward head posture and neck extension with rounded shoulders as the body weight collapses on the support (Keller et al., 1998).

General disadvantages of chair armrests in work tasks other than computer mouse use include limited access to keyboard and desk surface due to the length of the chair armrests (Lueder, 1986; Paul et al., 1996). Casual observations in a work setting also demonstrate that PC operators lean on armrests with a flexed elbow during conversation. This places pressure through the elbows where the ulnar nerve is susceptible to pressure.

In summary, ergonomics research supports the use of chair armrests during mouse use when examining the effect on static loading and fatigue of the shoulder and forearm muscles. This research has also shown user preference for armrests. However, there is a concern among ergonomists that chair armrests can increase physical risk factors during mouse use, as well as other work tasks. The ergonomics research cited addresses only a few of the physical risk factors associated with mouse use and chair armrests as shown in Table 1. These include static muscle loading of the shoulder and wrist muscles, and self-ratings of body discomfort. There still remains a number of risk factors that have not been studied in the ergonomic literature including the effect of chair armrests on wrist posture, contact pressure, and operator technique.

Related studies are available in the literature on PC operators, however, it is difficult to apply the findings from these studies since they do not specifically address computer mouse use with and without chair armrests. Some studies evaluate the use of forearm support during a different type of task such as keyboarding (Erdelyi et al., 1988; Haaglund & Jacobs, 1996; Hedge & Powers, 1995; Nakaseko et al., 1985). Other researchers have looked at a different area of support during computer mouse use such as the mouse wrist support and its effect on wrist posture (Damann & Kroemer, 1995). No studies have looked at comparing wrist postures, points of contact, or operator technique with or without proximal support such as the chair armrest during computer mouse use.

Study Objective

Chair armrests are commonly used in the workplace to support the upper extremity during mouse use. Although the literature has supported the use of fully-adjustable chair armrests with rotation features for reducing the muscle activity of the shoulder and forearm, concerns have been raised among ergonomic professionals regarding the possible risk factors the chair armrest might have on wrist postures, operator technique, and contact pressure of the upper extremity.

Table 1

Summary of Research Findings on Physical Risk Factors and Use of Chair Armrests During Computer Mouse Use.

Physical risk factors	Positive effect	Negative effect	Not studied
Static posturing /shoulder	Karlqvist et al., 1998 Paul et al., 1996 Wells et al., 1997		
Static posturing/wrist	Paul et al., 1996 Wells et al., 1997		
Awkward postures/shoulder	Karlqvist et al.,1998		
Awkward postures/wrist			x
Contact pressure/ points of contact			x
Operator technique			x
Arm fatigue/body discomfort	Attwood, 1986 Paul et al., 1996 Wells et al., 1997		
Performance (speed/accuracy)	Karlqvist et al.,1998		
User preference	Karlqvist et al., 1998 Paul et al., 1996 Wells et al., 1997		

Note. Results of chair armrest studies are categorized whether chair armrests had a positive effect, negative effect, or were not studied.

The objective of this study was to determine whether the use of height, width, and rotation-adjustable chair armrests during computer mouse use has an effect on (a) non-neutral wrist postures, (b) operator technique, and (c) points of contact of the right arm during computer mouse use. Subjective evaluation on perceived exertion, comfort, performance, and whether the PC operator preferred using a chair armrest or no armrest during mouse use was also determined. Results of the study will assist ergonomists, employers, and employees in understanding whether the chair armrest will increase CTD risk factors. Results can be considered with other available research studies when deciding whether or not to recommend using a chair armrest during computer mouse use to minimize these CTD risk factors.

The study was a mixed-factors design with two independent variables. The within-subjects variable was armrest condition (with and without chair armrests); the between-subjects variable was armrest experience (armrest user or nonuser). Six dependent variables were measured including (a) wrist posture (percentage of time spent in awkward wrist postures), (b) points of contact, (c) operator technique (including identifying if shoulder motion was present and the quality of motion while maneuvering the computer mouse), (d) fatigue, (e) body discomfort, and (f) preference. There were 20 computer operators in the study who participated in a mouse-based task for 18 minutes with intermittent keyboard use (two 2-minute sessions) for each condition. It is hypothesized that:

1. There will be no significant difference in wrist ROM (percentage of time in awkward wrist postures) with and without chair armrests during computer mouse use.

2. There will be no significant difference in wrist ROM (percentage of time in non-neutral postures) between PC operators who use a chair armrest in their work setting and those who do not use a chair armrest.

3. There will be a significant difference in points of contact of the upper extremity during mouse use. Use of a chair armrest will include a greater number of points of contact.

4. There will be no significant difference in quality of shoulder motion used to maneuver the mouse with and without chair armrests. Due to the PC operator's tendency to use external support, whether it be a chair armrest or the mouse work surface, movement at the shoulder will be minimal with greater motion at the distal upper extremity (wrist and fingers).

5. There will be a significant difference in fatigue and body discomfort with and without chair armrests during mouse use. Participants will have decreased fatigue and body discomfort ratings when using the chair armrest.

6. There will be no significant difference in subjective performance with and without chair armrests during mouse use.

7. There will be a significant difference in preference between the two conditions: with and without chair armrests. Participants will prefer the armrest condition with greater arm support.

METHOD

Participants

Twenty participants in the study were recruited from San Jose State University, a temporary employment agency, and local businesses. Participants were screened by questionnaire (Appendix D) prior to initiating the study. Criteria for participant selection included:

1. All participants were 18 years of age or older.
2. Participants had a minimum of one year of PC experience and used the right hand during computer mouse use.
3. Participants had experience playing the computer game, *Solitaire*.
4. There were an equal number of participants who used chair armrests and did not use chair armrests in their work setting during computer mouse use.
5. There was no recent history of upper extremity CTDs or upper extremity surgery in the last year.

All participants were paid $10.00 to $15.00 per hour to participate in the study. Written consent was obtained prior to data collection (Appendix E). Participants were told the purpose of the study was to evaluate the use of armrests during computer use. No reference to wrist posture measurement was made in an effort to prevent biased behavior.

Experimental Design

The experiment was a mixed-factors design with two independent variables: (a) armrest condition and (b) armrest experience. There were two levels of each independent variable: (a) chair armrests were either present or absent and (b) participants either had experience or no experience using chair armrests during mouse use. The dependent variables included (a) wrist range of motion, (b) points of contact of the right upper extremity, (c) operator technique, (d) fatigue, (e) body discomfort, and (f) preference. The following sections will describe each of the dependent variables and the method of measurement.

Wrist range of motion. This measurement included identifying the percentage of time spent in each interval of range of motion for (a) wrist flexion, (b) wrist extension, (c) wrist radial deviation, and (d) wrist ulnar deviation. Intervals of wrist posture were categorized into (a) neutral posture (0° to 15°), (b) moderate awkward posture (15° to 30°), and (c) extreme awkward postures (30+°).

Points of contact of the upper extremity. This analysis included identification of the areas of the upper extremity in contact on the armrest and/or mouse pad surface including the (a) elbow, (b) proximal forearm, (c) mid-forearm, (d) distal forearm, and (e) volar wrist throughout the testing session. A minimum of one inch of skin surface must have been in contact with the armrest or mouse pad surface to be considered a point of contact.

Operator technique. This measure involved observation of right upper extremity (shoulder) motion during three computer mouse tasks. Right upper extremity motion was classified into three categories based on the recommendations by Pascarelli & Quilter (1994), stating that the shoulder, in addition to the wrist should be used to maneuver the mouse. The categories included:

(a) Good: Good shoulder motion was defined by smooth motion initiated from the shoulder joint to maneuver the mouse. Wrist motion was also used, however, the primary motion occurred at the shoulder joint when larger cursor motion was required.

(b) Fair: Fair shoulder movement was defined by limited or restricted motion initiated from the shoulder for large cursor movements. Wrist motion was also used to maneuver the mouse.

(c) Poor: Poor shoulder motion was defined as little or no shoulder motion, with the computer mouse being primarily maneuvered by the wrist and digits.

In summary, smooth (good) shoulder motion represented the ideal computer mouse technique, while restricted (fair) or no shoulder motion (poor) represented greater risk based on ergonomic recommendations in the literature (Pascarelli & Quilter,1994)

Subjective evaluation of fatigue and body discomfort. This measurement included subjective ratings of body discomfort and fatigue level before and after each condition. A Likert scale was used to identify level of fatigue for the pretest (Appendix G) and posttest for each of the two conditions (Appendixes H and I). Five verbal anchors were used corresponding to a category-ratio scale (Hulley & Cummings, 1988). Participants were asked to circle the response that represented their level of fatigue. A questionnaire by Corlett and Bishop (1976) was modified and used to evaluate body discomfort in the right upper extremity, and left neck and shoulder region for male and female participants (Appendixes J and K). Ratings on a scale of 0 to 4 (0 = no discomfort; 4 = severe discomfort) were used to identify levels of discomfort.

Subjective evaluation of preference and performance. A two-part questionnaire was designed by the researcher to identify subjective preference and performance between the two conditions. The first part of the questionnaire measured subjective opinions on (a) comfort, (b) speed, (c) accuracy, (d) points of contact, (e) arm relaxation, and (f) positioning of chair armrests (Appendix L). The second part of the questionnaire assessed preference between the armrest conditions. Participants chose (a) preference for chair armrests, (b) preference for no chair armrests, or (c) no preference between the conditions while using the computer mouse (Appendix M).

Instrumentation

Wrist posture measurement. The Greenleaf WristSystem™ was used for static measurements of the wrist and to analyze dynamic wrist motion during the computer mouse tasks (Appendix N). Estimated error for accuracy and reliability of the Wristsytem's sensors is 2.5% for 120° range of motion. There were two 18-minute periods of data collection for wrist posture (one 18-minute period for each condition) with the Greenleaf Wrist System™. Wrist sensor gloves were worn by all subjects. Wrist movements were recorded at 6 Hz. The data transferred from the Greenleaf data recorder into a Macintosh hard drive. Greenleaf's Movement

Analysis System™ (MAS) software was used to interpret and display the recorded data.

Assessment of points of contact and operator technique of the upper extremity. A video camera was used to analyze points of contact and operator technique during the work task. The camera was set up to view the trunk and right upper extremity at a horizontal plane. Participants were videotaped throughout the entire session. Pictures were also taken with a 35 mm camera throughout the testing sessions.

Workstation Setup

The workstation setup included a bi-level adjustable computer table. Monitor height and keyboard height and depth were adjustable. A PC computer setup with a 21-inch monitor and standard 101 keyboard was used for testing. A standard Logitech mouse (Appendix O) with an 8-inch by 10.5-inch by ¼-inch mouse pad was positioned to the right and adjacent to the keyboard. Mouse pointer speed was set at midrange. An ergonomic chair manufactured by Neutral Posture Ergonomics, Inc. with three-way adjustable armrests was used (Appendix P). Chair armrests were 10 inches long and fully adjustable with height, width, and angle adjustment features. The armrests rotated 360° with the ability to position the armrest backward to allow for closer access to the work surface. The armrest was also designed to allow for a simultaneous change in armrest slope with adjustment of the seat pan (i.e., backward tilt of the seat angle resulted in a positive slope of the armrest; forward tilt resulted in a slight negative tilt of the armrest). Refer to Figure 3 for a schematic drawing of the workstation setup.

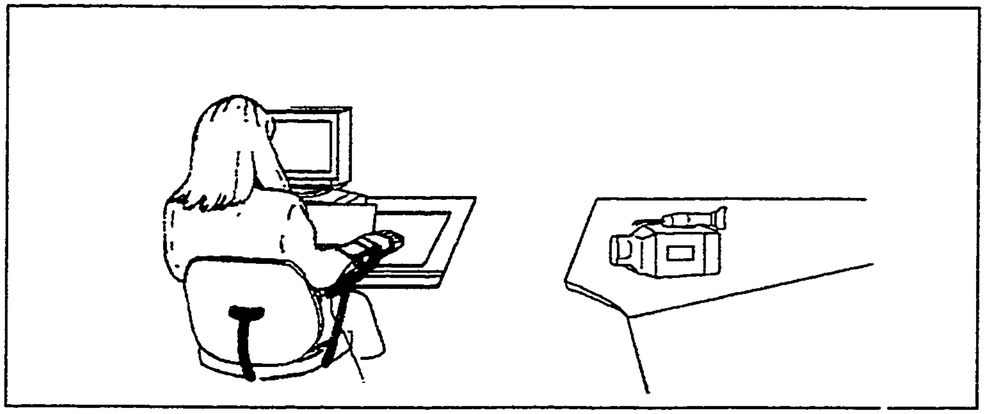

Figure 3. Schematic drawing of the workstation setup in the chair armrest experiment. Modified with permission of Lena Karlqvist (1998).

Computer Task

The computer task consisted of playing Solitaire and performing custom mouse-based tasks developed by Interface Analysis Associates. The tasks required 18 minutes of mouse use (with no simultaneous keyboard use) and 4 minutes of intermittent keyboard use typing text on the Word program. No data were collected during the keyboard tasks. Pointing tasks required the following cursor movement and mouse functions to complete each task:

1. Solitaire: Vertical, horizontal, and diagonal cursor movement with point/click, point/double-click, and click/drag functions in the upper two-thirds of the display screen.
2. Corner tasks: Cursor movement from the upper right-hand corner to the lower left corner of the display screen with point/click functions.
3. Clicker: Cursor movement in the upper left half of the screen with point/click mouse functions (Appendix Q).

4. Dragster: Cursor movement from the bottom of the screen to the upper half of the display screen requiring point/click and vertical and diagonal click/drag mouse functions (Appendix R).

5. Scroller: Cursor movement in vertical and horizontal directions with scrolling on the right side of the display screen. Point/click and click/drag mouse functions were required (Appendix S).

6. Vertical Drag: Cursor movement from the top quarter of the screen to three-fourths of the display screen. Point/click and vertical click/drag mouse functions were required (Appendix T). The task was added to the computer task protocol for the last 15 subjects to allow for measurement and comparison of one computer task only across armrest conditions.

Procedure

Armrest users and armrest nonusers were randomly assigned into two groups to determine order of presentation for armrest condition (with chair armrests or no chair armrests). The order of presentation for armrest condition was counterbalanced for each armrest experience group to control for practice effects. Participants were allowed to adjust the workstation to their comfort for the first armrest condition presented. Instructions were given by the researcher on how to adjust the bi-level table (keyboard height and depth, monitor height) and chair including (a) chair height, (b) chair back angle, (c) seat angle, and (d) chair armrests (experimental condition one). In condition two (without chair armrests), the chair armrests were removed from the chair. Only mechanical instructions were given (see Appendix U). Participants were asked to center on the keyboard alpha keys during the computer task. Each participant was allowed to work for 5 minutes at the workstation to confirm the setup was comfortable. Adjustments to the workstation were allowed during the trial period.

After adjustments were completed, a pretest measurement of arm fatigue and body discomfort was administered to establish a baseline level. The forearm was marked in thirds by the researcher to identify the (a) proximal, (b) middle, and (c) distal forearm for identification of points of contact on the forearm. Each participant was then fitted with the proper sized wrist glove for the Greenleaf Medical WristSystem™ (small, medium, or large). Two of the three straps on the gloves were modified to minimize interference with movement. The radial and ulnar styloids were used as landmarks for correct application of the glove. Wrist motions were calibrated for wrist flexion/extension and radial/ulnar deviation for the right hand. All calibrations were performed by the same researcher.

Prior to initiating the testing session, the researcher reviewed the pointing tasks with the participant. Baseline fatigue and body discomfort questionnaires were also administered. A static wrist measurement with the hand on the computer mouse was taken using the Greenleaf WristSystem™ for the first 20 seconds.

Participants were then instructed to begin the computer tasks alternating between keyboard and mouse use. The testing period for each condition lasted 22 minutes. Subjects were allowed to work at a self-directed pace. A questionnaire specific to each condition was administered at the end of each testing condition to determine level of fatigue and body discomfort. A 15-minute rest break was given between sessions.

On the second condition tested (with or without chair armrests), the same procedures were followed as in the previous condition tested, except participants were not allowed to adjust the chair or workstation heights. Preference between the two conditions was measured after both conditions were tested. Videotapes were analyzed for points of upper extremity contact and operator technique (Appendix V).

In summary, there were two periods of data collection and a total of four measurements of fatigue and body discomfort. Preference between the two conditions was indicated following the two data collection sessions. Refer to Figure 4 for the testing and data collection protocol.

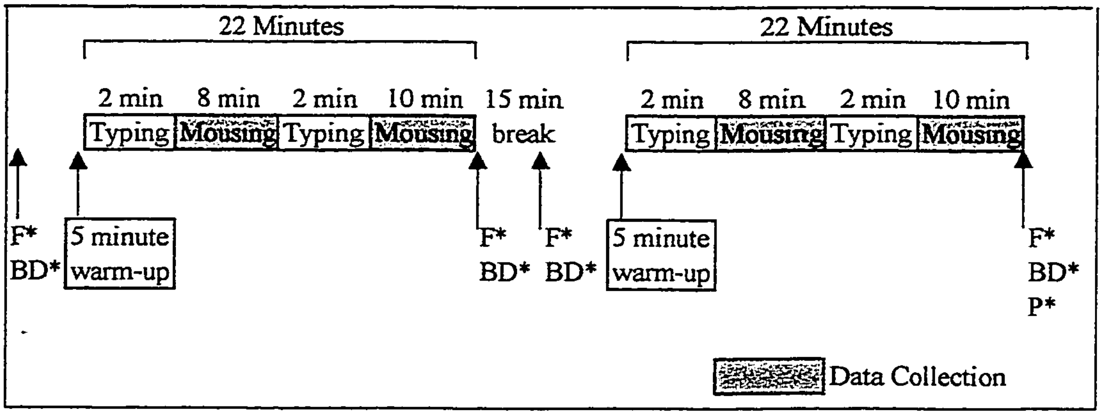

Figure 4. Testing and data collection protocol for the chair armrest study. After a 5-minute trial period for each workstation setup (with or without chair armrests), there were two 18-minute periods of data collection (DC) to assess (a) wrist posture, (b) points of contact, and (c) operator technique using the Greenleaf WristSystem™ and a video camera. Subjective fatigue (F*) and body discomfort ratings (BD*) were taken before and after each DC period. Preference (P*) between the two conditions and subjective assessment on performance with chair armrests were evaluated at the end of the two testing periods.

RESULTS

Twenty participants (13 females and 7 males) between the ages of 18 and 64 years (M=28.7 years) participated in the research project. The participants had an average of 9.6 years of experience using a PC computer. No participants had been formally trained in computer workstation ergonomics.

Data Analysis for Wrist ROM

Wrist extension, flexion, ulnar deviation, and radial deviation were measured during computer mouse use. Wrist flexion and radial deviation were not included in the statistical analyses since no wrist flexion was measured during any of the computer mouse tasks, and radial deviation was measured in the non-neutral posture category (15+°) for one participant only. A mixed-factors analysis of variance (ANOVA) with one within factor (armrest condition) and one between factor (armrest experience) was used to test the dependent variable, wrist posture.

Data were compiled for the following mouse tasks:

1. Four Mouse Tasks Combined. Data for 20 subjects were compiled for each of the computer mouse tasks: (a) Solitaire (3 sessions), (b) Scroller, (c) Point & Click/ Corner Tasks, and (d) Dragster for the factors, armrest condition and armrest experience. This data was considered the primary analysis in the experiment.

2. Vertical Drag. This mouse task was added to the protocol for the last 15 subjects and analyzed separately for the factors, armrest condition and armrest experience. This data was considered the secondary analysis in the experiment since it analyzed only one task for a limited number of subjects.

Statistical analyses using the SPSS software program were performed. Alpha level was set at .05. The analyses included manipulation of the factors, armrest condition and armrest experience for the following categories. A higher percentage of time in the non-neutral posture category was considered a greater risk.

1. Analysis of time spent in moderate and extreme non-neutral wrist categories combined > 15°. This analysis included calculation of the total percentage of time spent in both the 15° to 30° moderate non-neutral posture category and the 30+° extreme non-neutral posture category.

2. Analysis of time spent in the moderate non-neutral wrist posture category (15° to 30°).

3. Analysis of time spent in the extreme non-neutral wrist posture category (30+°).

A higher percentage in the 30+° category was considered a higher risk condition. A minimal percentage of time was spent in 30+° ulnar deviation category ranging from 0% to 1.21%, and therefore, was combined with the 15° to 30° category in the statistical analyses for ulnar deviation.

4. Analysis of the interaction between the two factors: armrest condition and armrest experience.

Wrist Extension – Four Mouse Tasks Combined

Armrest condition. There was a significant main effect for time spent in the non-neutral wrist extension range (> 15°) for armrest condition. The WITHOUT Armrest condition yielded a greater percentage of time in non-neutral wrist extension postures (91.32%) than the WITH Armrest condition (79.11%), $F(1, 18) = 5.75$, $p < .03$ (see Figure 5). When analyzing the individual moderate and extreme non-neutral categories, there was no significant effect for the moderate non-neutral posture category (15° to 30°) for the WITH Armrest condition (60.9%) compared to the WITHOUT Armrest condition (62.29%). In the extreme non-neutral posture category (30+°), no significant effect was found in the WITH Armrest condition (18.18%) when compared to the WITHOUT Armrest condition (29.03%).

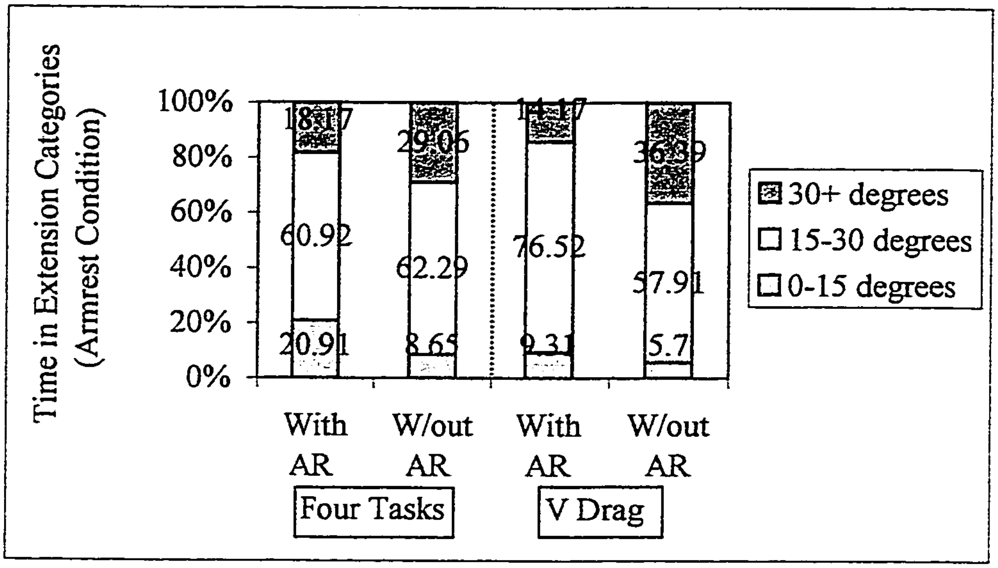

Figure 5. Summary of time spent in wrist extension categories in Four Mouse Tasks Combined and Vertical Drag for the factor, Armrest Condition.

Armrest experience. There was no overall main effect for time spent in non-neutral wrist extension range (> 15°) as a function of armrest experience. Armrest USERS spent 79.48% of the time in non-neutral wrist extension posture in both armrest conditions when compared to Armrest NONUSERS (90.96%) (see figure 6). When analyzing the individual moderate and extreme non-neutral categories, there was a significant main effect for the percentage of time spent in the moderate non-neutral posture category (15° to 30°). Armrest NONUSERS (73.74%) spent more time in the moderate non-neutral category than the Armrest USERS (49.48%): $\underline{F}$ (1,18) = 6.27, $\underline{p} < .02$. Although the Armrest USERS spent less time in the moderate category, it should be noted that Armrest USERS spent more time in the extreme non-neutral posture category (30+°). However, no significant effect was found for percentage of time spent in non-neutral wrist extension postures for Armrest USERS (30%) versus Armrest NONUSERS (17.2%).

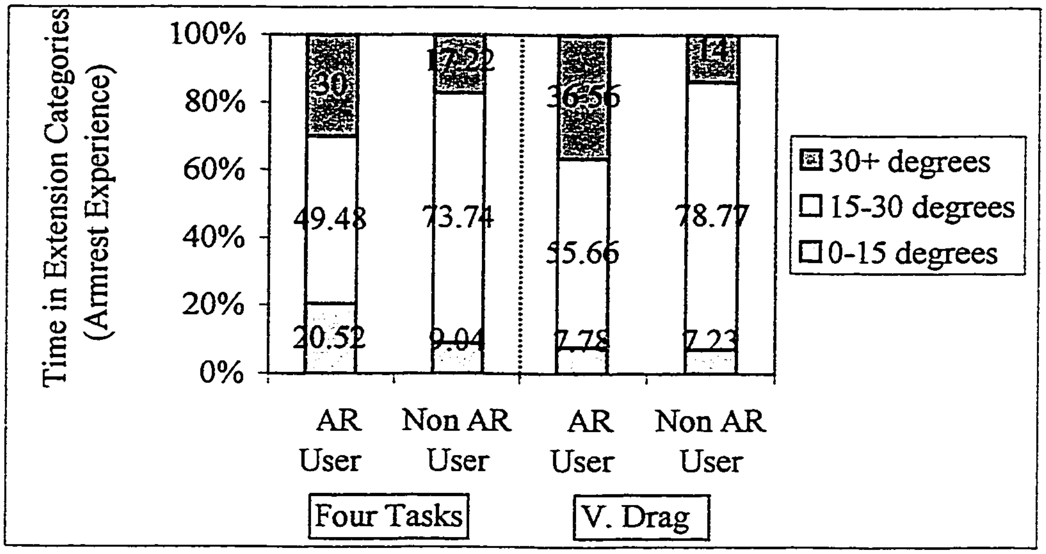

Figure 6. Summary of time spent in wrist extension categories for Four Mouse Tasks Combined and Vertical Drag for the factor, Armrest Experience.

Interaction: No interaction between armrest condition and armrest experience was found when comparing time spent in non-neutral extension range (> 15°) or the moderate (15° to 30°) and extreme posture category (30+°).

Wrist Extension -Vertical Drag

Armrest condition. There was no main effect for overall time spent in non-neutral wrist extension postures (>15°) when comparing the WITH Armrest condition (90.69%) and the WITHOUT Armrest condition (94.3%). When analyzing the individual non-neutral categories, there was no significant effect for the moderate non-neutral posture category (15° to 30°) for the WITH Armrest condition (76.52%) compared to the WITHOUT Armrest condition (57.91%). In the extreme non-neutral posture category (30+°), no significant effect was found in the WITH Armrest condition (14.17%) when compared to the WITHOUT Armrest (36.39%) (see figure 5).

Armrest experience. There was no overall main effect for time spent in non-neutral wrist extension range (> 15°) for the factor, Armrest Experience. Armrest USERS spent 92.22% of the time in non-neutral wrist extension posture in both armrest conditions when compared to Armrest NONUSERS (92.77%) (see figure 6). When analyzing the individual non-neutral categories, there was no significant effect for the percentage of time spent in the moderate non-neutral posture category (15° to 30°) for Armrest USERS (78.77 %) and Armrest NONUSERS (67.22%). In the extreme non-neutral posture category (30+ °), no significant effect was found for Armrest USERS (36.56%) and Armrest NONUSERS (25.28%).

Interaction. The interaction of the factors, Armrest Experience and Armrest Condition was significant for wrist extension > 15° in the individual mouse task, Vertical Drag: $F\ (1,13) = 6.62$, $p < .02$ (see figure 7). In order to identify the source of the significant Armrest Condition * Experience interaction, simple effects analyses (within-subjects) were conducted examining the effect of Armrest Condition separately for each Armrest Experience condition. Although the simple effect of Armrest Condition was not significant for Armrest NONUSERS, the Armrest USERS yielded a greater percentage of time in non-neutral wrist extension posture in the WITHOUT Armrest condition (97.39%) when compared to the WITH Armrest condition (87.02%): F (1,9) = 7.7, $p < .02$. In summary, PC operators with armrest experience spent less time in non-neutral wrist extension postures when using a chair armrest. There was no difference in percentage of time spent in non-neutral wrist extension >15° for PC operators without armrest experience across armrest condition for the one mouse task, Vertical Drag.

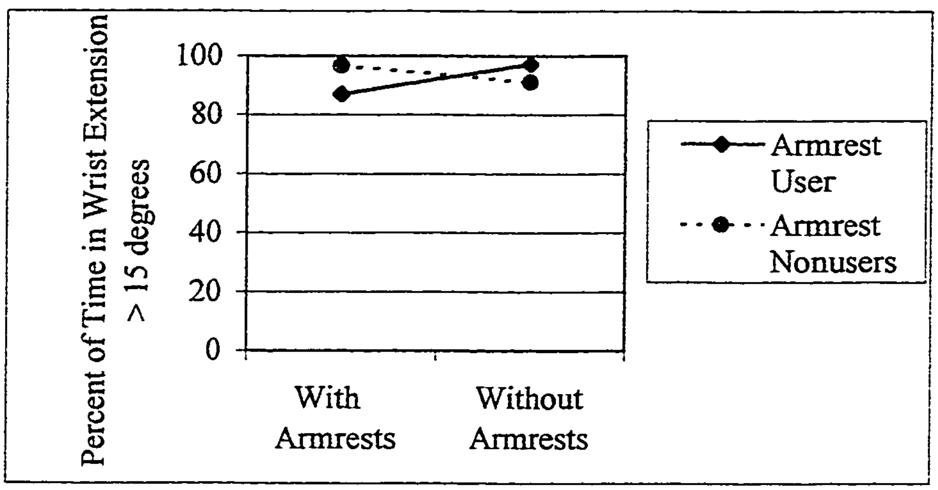

Figure 7. Interaction between the factors, Armrest Condition and Armrest Experience, for the percentage of time spent in wrist extension > 15° in the mouse task, Vertical Drag.

Summarizing the results for wrist extension in the four mouse tasks combined, when using armrests, participants spent less time in non-neutral wrist postures > 15° when compared to without armrests. No significant difference was noted with or without chair armrests for Vertical Drag for non-neutral wrist extension posture > 15°. There was no difference when analyzing each of the non-neutral wrist posture categories (15° to 30° and 30+°) for the within-subjects factor, armrest condition. The between-subjects factor, armrest experience, did show a significant difference in the 15° to 30° category. Armrest USERS spent less time in the moderate non-neutral wrist posture category for both armrest conditions when compared to armrest NONUSERS. However, since armrest users also spent more time in the 30+° category (findings were nonsignificant), it is not accurate to conclude that armrest USERS spent less time in non-neutral wrist postures based on these findings. There was an interaction between Armrest Condition and Armrest Experience for Vertical Drag only in the analysis of wrist extension posture > 15°. The operators with armrest experience spent less time in non-neutral wrist postures when using a chair armrest when compared to not using a chair armrest. There was no significant difference in percentage of time spent in non-neutral postures when comparing armrest conditions for operators without armrest experience.

Ulnar Deviation – Four Mouse Tasks Combined

Armrest condition. There was a significant main effect for overall time spent in non-neutral wrist ulnar deviation (> 15°) for Armrest condition. The WITHOUT Armrest condition yielded a greater percentage of time in non-neutral wrist ulnar deviation (37.85%) than the WITH Armrest condition (29.8%), $F(1, 18) = 7.25$, $p < .02$ (see Figure 8).

Armrest experience. There was no main effect for time spent in non-neutral wrist ulnar deviation range (> 15°) in both armrest conditions for the factor, Armrest Experience. Armrest USERS spent 30.45% of the time in this range compared to 37.2%

for Armrest NONUSERS (see Figure 9).

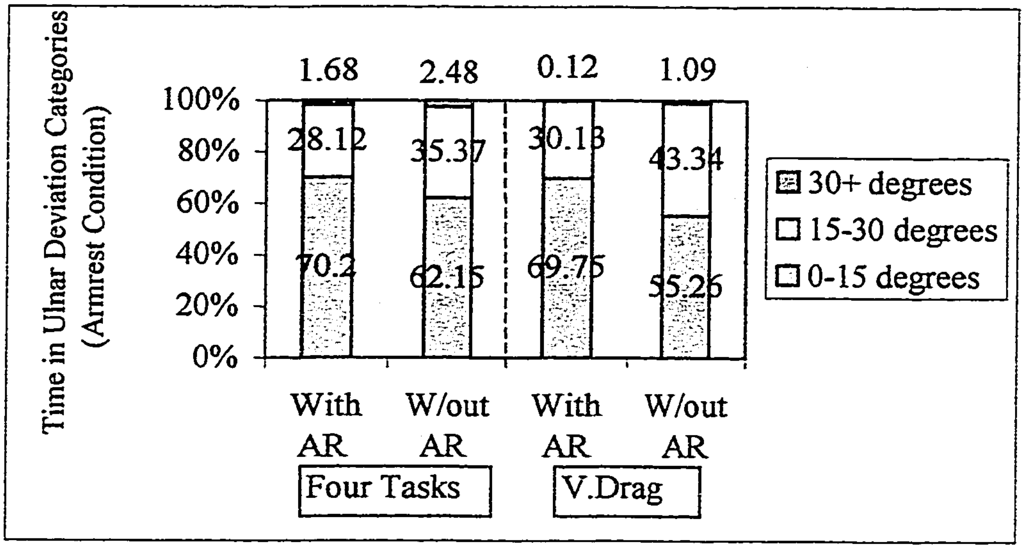

Figure 8. Summary of time spent in wrist ulnar deviation categories for Four Mouse Tasks Combined and Vertical Drag for the factor, Armrest Condition.

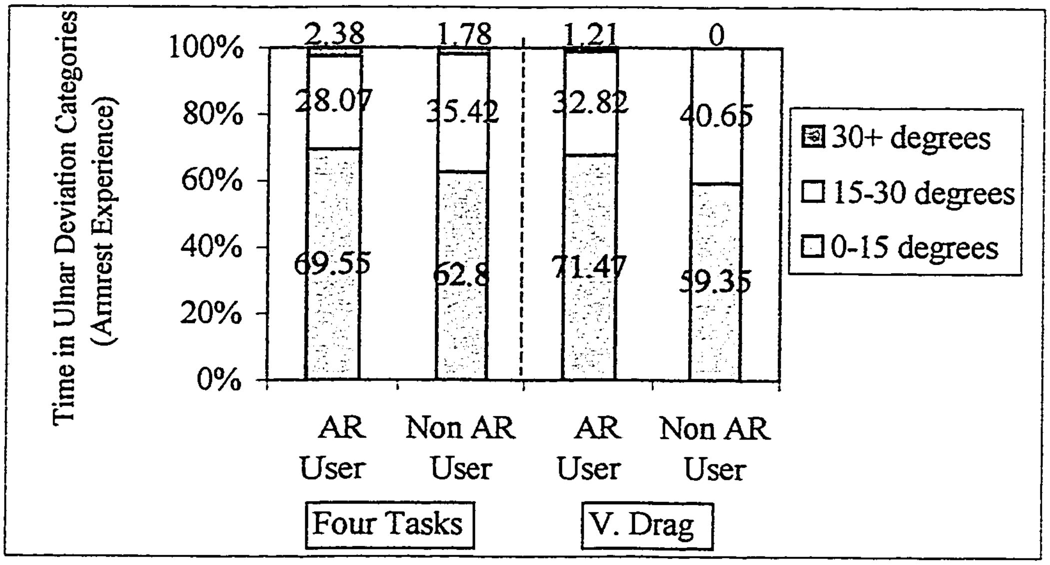

Figure 9. Summary of time spent in wrist ulnar deviation categories for Four Mouse Tasks Combined and Vertical Drag for the factor, Armrest Experience.

Interaction. The interaction of the factors, Armrest Experience and Armrest Condition, was significant for ulnar deviation > 15° in the four mouse tasks combined: $F(1,18) = 6.2$, $p < .02$ (see figure 10). In order to identify the source of the significant Armrest Condition * Experience interaction, simple effects analyses (within-subjects) were conducted examining the effect of Armrest Condition separately for each level of Armrest Experience. Although the simple effect of Armrest Condition was not significant for Armrest USERS, the Armrest NONUSERS yielded a significantly greater percentage of time in non-neutral ulnar deviation posture in the WITHOUT Armrest condition (44.93%) when compared to the WITH Armrest condition (29.45%): $F(1,9) = 9.53$, $p < .02$. In summary, the source of the significant interaction for non-neutral ulnar deviation >15° in the four mouse tasks combined was from the significant simple effect found for armrests NONUSERS. Armrest NONUSERS spent less time in non-neutral deviation postures when using a chair armrest compared to not using an armrest. There was no difference in percentage of time spent in non-neutral ulnar deviation postures for armrest USERS.

Ulnar Deviation – Vertical Drag

Armrest condition. There was no significant main effect when comparing the time spent in non-neutral wrist ulnar deviation postures > 15° in the WITH Armrest condition (30.25%) versus the WITHOUT Armrest condition (44.43%) (see figure 8).

Armrest experience. There was no significant main effect for time spent in non-neutral wrist ulnar deviation range > 15° in both armrest conditions for the factor, Armrest Experience. Armrest USERS spent 34.03% of the time in this range compared to 40.65% for Armrest NONUSERS (see Figure 9).

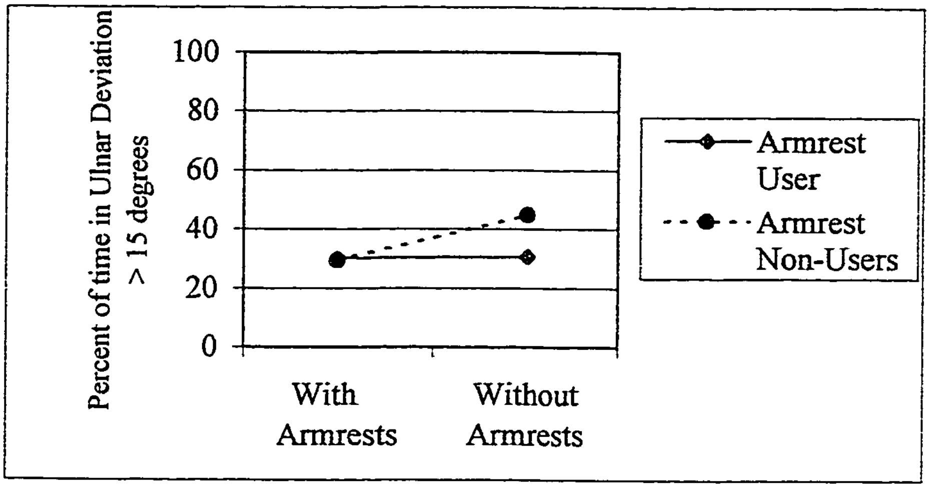

Figure 10. Interaction between the factors, Armrest Condition and Armrest Experience, for percentage of time spent in ulnar deviation > 15° for Four Mouse Tasks Combined.

Interaction. The interaction of the factors, Armrest Experience and Armrest Condition, was not significant for ulnar deviation > 15° in the one mouse task, Vertical Drag.

Summarizing the results for wrist ulnar deviation, operators using the chair setup without chair armrests spent a greater time in non-neutral wrist postures > 15° when compared to using the chair setup with chair armrests for the four mouse tasks combined. No significant difference was noted for the one mouse task, Vertical Drag. There was no significant difference for the between-subjects factor, Armrest Experience, for both analyses (four mouse tasks combined and Vertical Drag). An interaction was present between the factors, Armrest Condition and Armrest Experience, for the four mouse tasks combined. Armrest NONUSERS benefited from the use of chair armrests showing less time in non-neutral ulnar deviation postures in the WITH Armrest condition, whereas Armrest USERS showed similar (lower) percentages of time in non-neutral wrist postures with or without armrests.

Operator Technique

Videotapes of 18 participants were analyzed for three computer mouse tasks to identify if shoulder motion was present during computer mouse use in each of the armrest conditions. Categories of motion were categorized into three categories including (a) *Good* - smooth shoulder movement, (b) *Fair* - resisted or limited shoulder movement (i.e., increased wrist movement used simultaneously with limited or restricted shoulder motion), and (c) *Poor* - zero to slight shoulder motion with the computer mouse being primarily maneuvered by the wrist and/or digits. Tasks analyzed included (a) Corner Tasks for 18 participants, (b) Scroller for18 participants, and (c) Vertical Drag for 13 participants for a total of 49 observations for each armrest condition. Results were calculated for the factor, Armrest Condition only. Two videotapes were not analyzed due to technical error. A second observer evaluated the performance of three participants to confirm interobserver reliability prior to evaluating the remainder of the videotapes. Refer to Table 2 for a summary of findings.

In the WITH Armrest condition, 4 out of 49 observations (8%) used the shoulder with smooth motion (good rating) compared to 9 out of 49 observations (18%) in the WITHOUT Armrest condition; 24 out of 49 observations (49%) used limited or restricted shoulder motion (fair rating) with wrist motion in the WITH Armrest condition compared to 18 out of 49 observations in the WITHOUT Armrest condition (37%). Zero to slight shoulder motion with primarily wrist and digit motion to maneuver the mouse (poor rating) was used in 21 out of 49 observations (43%) in the WITH Armrest condition compared to 22 out of 49 observations (45%) in the WITHOUT Armrest condition.

Table 2. Number of Observations Rating Quality of Shoulder Motion for Three Computer Mouse Tasks for Armrest Condition

		Quality of Shoulder Motion		
Mouse Task	Condition	*Good* Smooth Motion	*Fair* Limited/ Restricted	*Poor* Zero to Slight Motion
PC & Corner (n =18)	With AR	3 out of 18	11 out of 18	4 out of 18
	Without AR	5 out of 18	7 out of 18	6 out of 18
Vertical Drag (n =13)	With AR	0 out of 13	4 out of 13	9 out of 13
	Without AR	2 out of 13	2 out of 13	9 out of 13
Scroller (n = 18)	With AR	1 out of 18	9 out of 18	8 out of 18
	Without AR	2 out of 18	9 out of 18	7 out of 18
Total = 3 Tasks	With AR	4 out of 49	24 out of 49	21 out of 49
	Without AR	9 out of 49	18 out of 49	22 out of 49

Note. Motion was classified into three categories including (a) smooth shoulder movement (good rating), (b) restricted/limited shoulder movement (fair rating), or (c) zero to slight shoulder motion with the computer mouse being primarily maneuvered by the wrist and/or digits (poor rating). Smooth shoulder motion was the recommended category of motion and use of the wrist/digits with zero to slight shoulder motion was the category of motion indicating the greatest risk based on ergonomic recommendations.

In summary, when comparing the number of observations for Armrest Condition, the WITHOUT Armrest condition had more number of smooth shoulder motion observations by 10% when compared to the WITH Armrest condition. It is interesting to note that the majority of observations were in the limited shoulder motion (24 observations WITH Armrests and 18 WITHOUT Armrests) and zero to slight shoulder motion only category (21 observations WITH Armrests and 22 observations WITHOUT Armrests), indicating that quality of shoulder motion in both armrest conditions was less than optimal.

Points of Contact

Points of contact of the upper extremity on the chair armrest or the mouse pad surface were identified for the factor, Armrest Condition. For the first analysis, the number of points of contact for each area of the right arm was calculated for all participants. Points of contact at the elbow and volar wrist were considered risk factors. For the second analysis, one category that represented the combination of points of contact on the armrest or mouse pad surface during the testing session was identified for each armrest condition.

As expected, when looking at the total number of individual points of contact for each armrest condition, the WITH Armrest condition had an increased number of points of contact (87 out of 100) when compared to the WITHOUT Armrest condition (39 out of 100) (see table 3). The number of points of contact at the elbow were greater in the WITH Armrest condition (10 out of 20) versus the WITHOUT Armrest condition (0 out of 20). The number of points of contact at the volar wrist was 18 out of 20 for the WITH Armrest condition and 20 out of 20 for the WITHOUT Armrest condition.

When looking at the categories of points of contact, 18 of the 20 participants (90%) in the WITHOUT Armrest condition were observed to have points of contact at the volar wrist and distal forearm during the testing session; 2 of the 20 participants of (10%) had contact at the mid-forearm, distal forearm, and wrist. No other combinations of points of contact were observed in the WITHOUT Armrest condition.

Table 3. Summary of Individual Points of Contact on the Right Arm for Armrest Condition.

Point of Contact	WITH Armrest	WITHOUT Armrest
Elbow	10 out of 20	0 out of 20
Proximal Forearm	20 out of 20	0 out of 20
Mid-Forearm	20 out of 20	1 out of 20
Distal Forearm	19 out of 20	18 out of 20
Volar Wrist	18 out of 20	20 out of 20
TOTAL	87 out of 100	39 out of 100

Note. Scores equal the number of points of contact. Total possible score is 20 points of contact (n = 20). A total of 100 points of contact was possible for each armrest condition. The lower number of points of contact overall is considered a lower risk.

In the WITH Armrest condition, 9 of the 20 participants (45%) were observed to have contact with the elbow, proximal forearm, mid-forearm, distal forearm, and wrist; 9 of the 20 participants (45%) had contact at the proximal forearm, mid-forearm, distal forearm, and wrist; one of the 20 participants (5%) had contact with the proximal forearm and mid-forearm only, and one participant (5%) had contact at the elbow, proximal, and mid-forearm. No observations were noted in the wrist only, wrist and distal forearm, and wrist, distal forearm, and mid-forearm categories. Refer to Figure 11 for a summary of categories of points of contact for the right arm in the chair armrest experiment.

In summary, when analyzing the categories of points of contact for each participant for the factor, Armrest Condition, greater points of contact were noted in the WITH Armrest condition due to forearm contact on the armrest. The WITH Armrest condition also had a greater overall number of individual points of contact. When analyzing the areas of risk, frequency of contact for the volar wrist was predominant in both conditions. This also shows that the chair armrest did not decrease the frequency of contact at the volar wrist even though proximal support was provided. As expected, the frequency of elbow contact was greater in the WITH Armrest condition, showing a greater risk when compared to the WITHOUT Armrest condition.

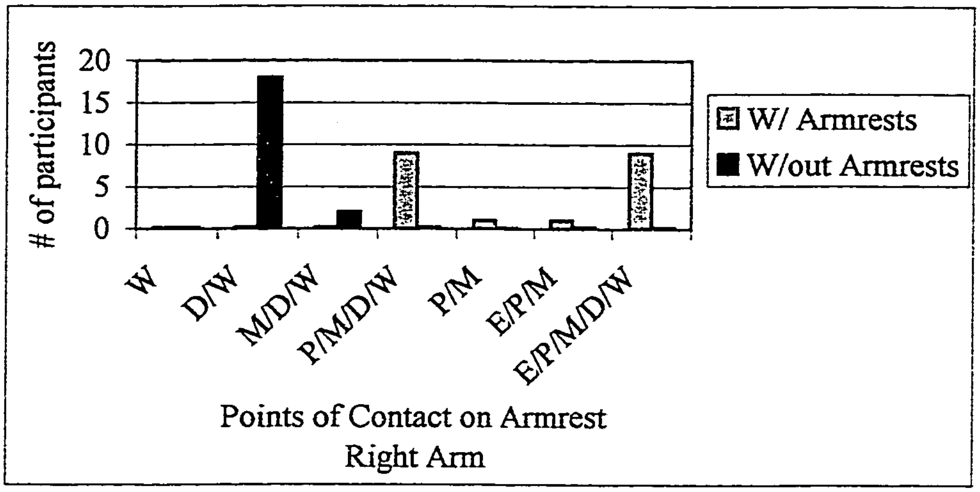

Figure 11. Categories of points of contact of the right arm on the chair armrest and mouse pad surface for the factor, Armrest Condition. Categories include (a) wrist only (W), (b) distal forearm and wrist (D/W), (c) mid- forearm, distal forearm and wrist (M/D/W), (d) proximal, mid and distal forearm and wrist (P/M/D/W), (e) proximal and mid-forearm (P/M), (f) elbow, proximal and mid-forearm (E/P/M), and (g) elbow, proximal, mid and distal forearm and wrist (E/P/M/D/W).

Fatigue

Subjective data on fatigue was collected for 20 participants before and after each armrest condition. Ratings were categorized and assigned a numerical value from 0 (no fatigue) to 4 (severely fatigued). The data were analyzed using the Wilcoxen Related Samples Signed-Ranks Test for (a) analysis of overall pretest fatigue ratings, and (b) analysis of posttest fatigue ratings for the factor, Armrest Condition.

Analysis of overall pretest scores showed that prior to each testing session, there was no significant difference in fatigue scores across armrest condition. Mean score for both the WITH Armrest and WITHOUT Armrest condition was 0.3. Since there was no significant difference in pretest scores, indicating the populations were the same, subsequent analyses focused on comparison of posttest ratings. Analysis of posttest scores showed that the WITH Armrest condition ($M = 0.6$) had significantly lower fatigue scores when compared to the WITHOUT Armrest condition ($M = 1.15$), $Z = 2.8$, $p < .05$. Overall scores ranged from 0 (no fatigue) to 2 (moderate fatigue) across conditions.

Discomfort

Pretest and posttest subjective discomfort ratings were collected for 20 participants for the right upper extremity and the left neck, upper back, and shoulder region before and after each armrest condition. Ratings were categorized from 0 (no discomfort) to 4 (severe discomfort). The data were analyzed using the Wilcoxen Related Samples Signed-Ranks Test for (a) analysis of overall pretest body discomfort ratings, (b) analysis of overall posttest body discomfort ratings, and (c) analysis of posttest individual body part discomfort ratings.

Prior to testing, there was no significant difference in discomfort scores across armrest condition (Z=.121, N. S.). Analysis of posttest scores showed that there was significantly lower discomfort scores when using armrests (M =.23) when compared to no armrests (M=.41), $Z = 2.67$, $p < .05$. Further analyses were performed to identify if armrest condition. A significant effect was noted for the right shoulder only ($Z = 2.60$,

$p < .05$). The three highest mean discomfort ratings across armrest conditions were noted in the WITHOUT Armrest condition for the right volar wrist ($M = .75$), right shoulder ($M = .65$), and the right volar forearm ($M = .60$). Volar wrist and forearm discomfort ratings could be attributed to fit of the WristSystem™ glove. Overall ratings ranged from 0 (no discomfort) to 2 (moderate discomfort) across conditions.

Preference

Subjective preference for armrest condition was evaluated for 20 participants. Overall, 19 of the 20 participants (95%) preferred using chair armrests during the computer task. One of the 20 participants preferred no chair armrest due to her familiarity with the chair setup. Further subjective assessment of performance and comfort factors related to chair armrest use were summarized (see Figure 12). Participants were given the option to choose (a) chair armrests, (b) no chair armrests, or (c) no difference noted between the conditions for each of the performance and comfort factors.

1. Comfort. All 20 participants (100%) reported that the chair armrests were more comfortable when using the computer mouse.

2. Speed. Thirteen of the 20 participants (65%) reported they were able to work faster when using the mouse with chair armrests; four participants (20%) reported working faster without chair armrests, and three participants (15%) reported they did not notice a difference in speed when working with the computer mouse.

3. Accuracy. Nine of the 20 participants (45%) reported that they felt their accuracy was greater when using the computer mouse with armrests; two participants (10%) felt that

accuracy with the computer mouse was greater without chair armrests; and 9 participants (45%) felt there was no difference in their accuracy when comparing both armrest conditions.

4. Arm relaxation. All 20 participants (100%) felt that their right arm was more relaxed when using the chair with armrests during computer mouse use.

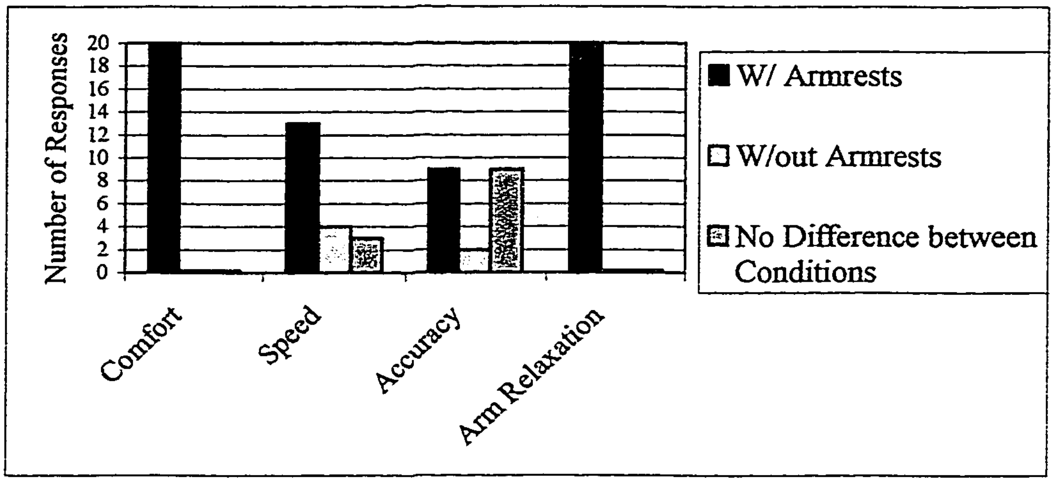

Figure 12. Summary of preference ratings for performance and comfort factors. Higher responses are indicative of preferred armrest condition.

Other factors related to functionality and comfort were evaluated by the questionnaire including (a) whether participants were able to position the chair armrests in their preferred setting, (b) if chair armrests interfered with keying, and (c) whether the chair armrests irritated the arm during mouse use (see Figure 13).

1. Positioning of chair armrest: Nineteen of the 20 participants (95%) reported they were able to position the chair armrests in the position they preferred when using the computer mouse; one participant (5%) was unable to position the chair armrest in the position he/ she preferred.

2. Armrest interference while keying. Seventeen of the 20 participants (85%) reported the chair armrests did not interfere with keyboard use; one participant (5%) reported the armrests did interfere with keying; and two participants (10%) reported they did not notice if the armrest interfered when using the keyboard.

3. Arm irritation. Fourteen of the 20 participants (70%) reported that the chair armrests were not irritating to their right arm when using the computer mouse; four participants (20%) reported chair armrests were irritating to the right arm, and 2 participants (10%) reported they did not notice whether the chair armrest was irritating to the right arm when using the computer mouse.

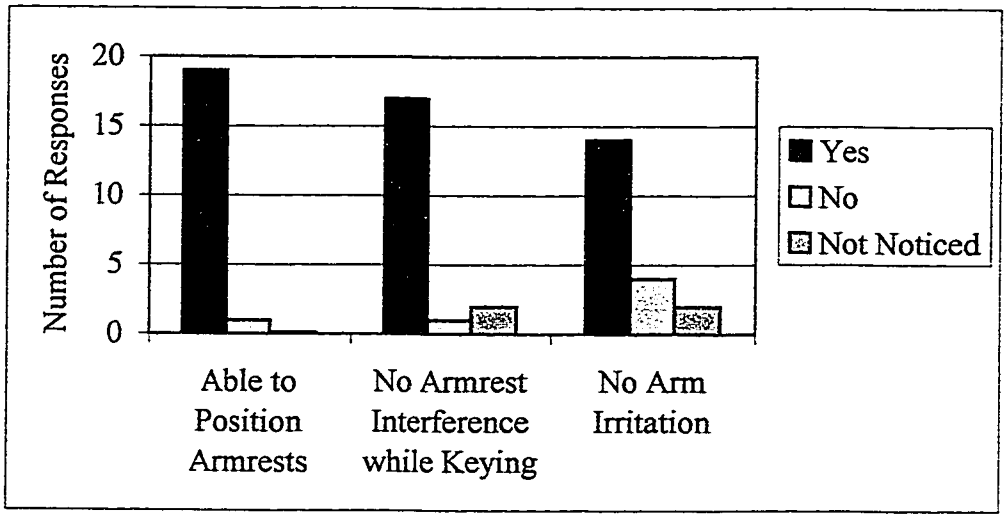

Figure 13. Summary of preference ratings for armrest functionality and comfort factors. Higher number of responses is indicative of positive rating.

Workstation Setup and Chair Armrest Heights

Descriptive data including means, minimum, and maximum values were calculated for the relationship between the chair armrest height, work surface height (keyboard + mouse pad), and sitting elbow height for 20 participants when using the chair armrests. (Refer to Table 4 for summary of descriptive data for work surface and armrest heights in relation to sitting elbow height during the chair armrest experiment.)

Table 4. Summary of Descriptive Data for Work Surface and Armrest Heights in Relation to Sitting Elbow Height.

Measurement	Mean Height Difference	Range
Work Surface Height to Elbow Height	+ 1.50"	+.25" - +3.0"
Armrest Height to Elbow Height	+ 2.08	+ .5" - +2.62"
Armrest Height to Work Surface Height	+ .54"	-.75" - +1.87"

Work surface height to elbow height. Work surface heights were set higher than sitting elbow height for all 20 participants. Work surfaces were set up between 1.25" and 3.0" (M = 1.50").

Chair armrest height to sitting elbow height. Chair armrests were set up between .5" and 2.62" higher than sitting elbow height (M =2.08").

Chair armrest height to work surface height. Armrest height ranged from .75" below the work surface height to 1.87" above the work surface height (M = .54"). Eighteen subjects set the armrest above work surface height and two subjects set the armrest below work surface height.

DISCUSSION

The purpose of this study was to examine wrist posture during computer mouse use with and without chair armrests. Analysis of time spent in non-neutral wrist posture categories (15° to 30° and 30+°) for extension and ulnar deviation was compared for the factors, armrest condition and armrest experience. Comparison of operator technique, points of contact on the right arm, body discomfort, fatigue, and preference were compared across armrest conditions. The following sections will discuss the results of the study.

Wrist Extension

The hypothesis stating that there would be no significant difference in wrist posture was not supported for wrist extension for the four mouse tasks combined. Participants showed a greater amount of time spent in non-neutral wrist extension postures when using a chair without armrests versus using a chair with armrests. When analyzing the additional single mouse task, Vertical Drag, the hypothesis was supported. That is, there was no significant difference in the amount of time spent in non-neutral wrist extension postures between armrest conditions when performing the Vertical Drag mouse task.

The interaction between the two factors was not significant for the primary analysis, four mouse tasks combined. However, the interaction between the two factors, armrest condition and armrest experience was significant for the one mouse task, Vertical Drag. The source of the significant interaction was for armrest users. It showed that PC operators with armrest experience spent less time armrests in non-neutral wrist extension posture when using chair armrests. While statistically significant, these data do not suggest a strong effect of prior armrest experience on wrist posture during computer mouse use since it was significant for only one mouse task, Vertical Drag.

What was equally significant in the analysis was the increased amount of time spent in non-neutral wrist extension postures >15°. For both armrest conditions, participants spent the majority of time in wrist extension >15°, a range which has been implicated in the literature as contributing to CTDs. When averaging the percentage of time spent in non-neutral wrist extension posture >15° for both analyses, the PC operators using chair armrests spent 85.22% of the time in wrist extension >15° and 92.82% of the time in wrist extension >15° when not using the chair armrest. Even though using chair armrests resulted in reduced wrist extension, both armrest conditions did not reduce the risk of non-neutral wrist extension postures for the PC operator. It was observed in this study that the absence or presence of a chair armrest during mouse use was not the sole contributing factor to increased wrist extension. Many factors, such as the difference in PC operator's technique, workstation setup including the keyboard and chair, mouse profile and anthropometrics contributed to wrist extension during computer mouse use in this study. The following sections describe the factors that can contribute to non-neutral wrist extension postures. Casual observations made throughout the study are described.

One of the factors that contributed to increased wrist extension was the downward slope of the forearm from the elbow to the volar wrist. It was observed during the study that the higher the elbow was in relationship to the volar wrist, and most often, the work surface, the greater the downward slope of the forearm (elbow joint to wrist joint). This slope resulted in greater wrist extension for some participants in both armrest conditions. This confirms the finding by Damann and Kroemer (1995) that the computer mouse should be located near elbow height during mouse use to minimize wrist extension. The elbow to volar wrist height measurement was influenced by (a) work surface and chair armrest height, (b) presence of shoulder hiking, (c) degree of forward reach, and/or (d) contact of the volar wrist on the mouse surface.

Work surface and chair armrest height. The majority of participants placed the work surface higher than sitting elbow height (M = +1.50"). However, when using a chair armrest, the sitting elbow height is no longer a factor since the arm is now resting on a chair armrest. Elbow heights were typically higher than the work surface height since the armrest was generally placed higher or equal to the work surface height (M = +. 5"; Range: - .75" to 1.87"). When PC operators placed the armrest higher than the work surface height and planted the volar wrist on the mouse pad surface, this created a downward slope resulting in increased wrist extension. When some PC operators placed the armrest lower than the work surface height, it appeared to increase the pressure at the volar wrist while operating the computer mouse.

When not using chair armrests, it would be assumed that placing the work surface height higher than elbow height would create an upward slope from the elbow to the volar wrist resulted in less wrist extension. This was true for some participants, however, for others, this was not observed. In the absence of using a chair armrest, these participants tended to hike the shoulder and extend the elbow. This tendency with a forward, extended reach for the mouse resulted in a downward slope from the elbow to the wrist, similar to using chair armrests (see Figure 14).

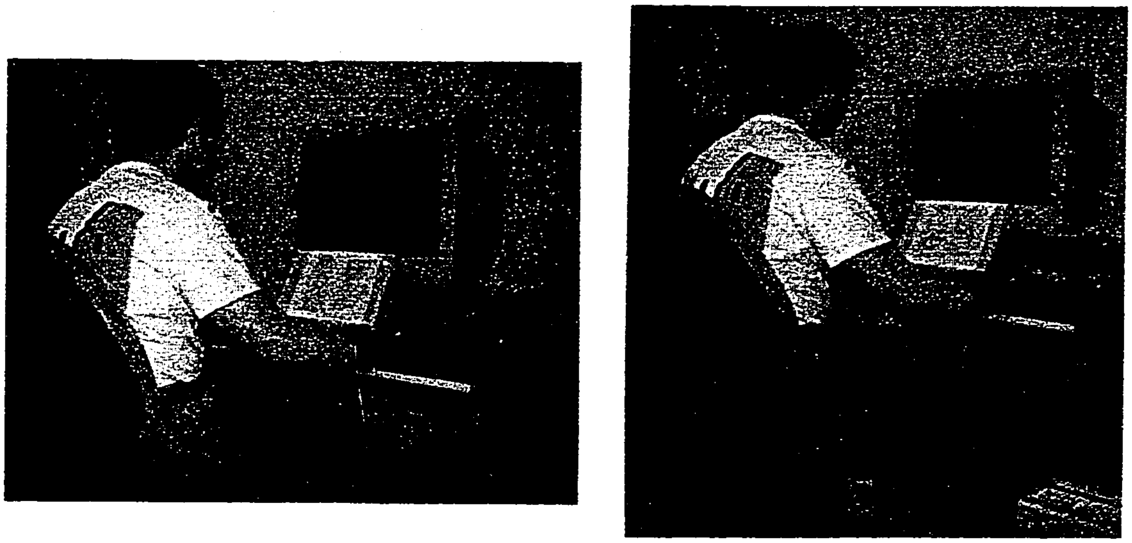

Figure 14. PC operator demonstrating downward slope of the lower arm in both armrest conditions.

It should be remembered that this example with both armrest conditions resulting in a downward slope was not the case for all participants. Some were able to relax the shoulder while using the mouse, resulting in a more level plane from the elbow to the wrist joint while others hiked the shoulder when not using a chair armrest. The same was true for the armrest condition. Some positioned the chair armrest equal to or slightly lower than the work surface resulting in an even plane with the work surface while others positioned the armrest higher resulting in a downward slope from the elbow to the volar wrist. Participants varied in their workstation and chair setup, effecting the elbow to volar wrist height, one of the factors contributing to wrist extension.

Forward and lateral reach. Forward and lateral reach of the right arm that is achieved primarily by shoulder flexion and abduction, contributes to increased wrist extension by increasing the elbow height in relation to the work surface height. Shoulder flexion and abduction is required to position the hand on the mouse to the right of the keyboard. Factors contributing to forward and lateral reach include sitting too far from the keyboard/mouse setup, body anthropometrics, body posture, and the location of the mouse on the mouse pad. It was observed that PC operators typically sat too far from the keyboard/mouse work surface and also maneuvered the mouse in the last one-half or one-third of the mouse pad, when it was not necessary. This increased reach resulted in an increased elbow height in relation to the volar wrist height, as well as a tendency to use the mouse surface for a support, resulting in increased wrist extension.

Planting at the volar wrist. Planting at the volar wrist on the mouse pad surface while using the computer mouse contributed to greater wrist extension for the majority of PC operators. Only two participants did not plant at the volar wrist when using the chair armrest. All participants planted at the volar wrist to operate the computer mouse when not using a chair armrest. Planting at the volar wrist increased wrist extension due to (a) contributing to an increased downward slope from the elbow to the volar wrist, (b) the mouse profile being higher than the work surface, resulting in wrist extension to position the hand on the mouse if the wrist is planted, (c) the PC operator's tendency to move through the wrist/digits to maneuver the mouse as opposed to the shoulder or a combination of joints once the wrist was planted on the mouse pad surface. Posturing of the hand with the distal palm held off the mouse also contributed to wrist extension. The two distal joints of the index finger were typically held in slight flexion, preventing the hand or distal palm from resting on the mouse (see figure 15).

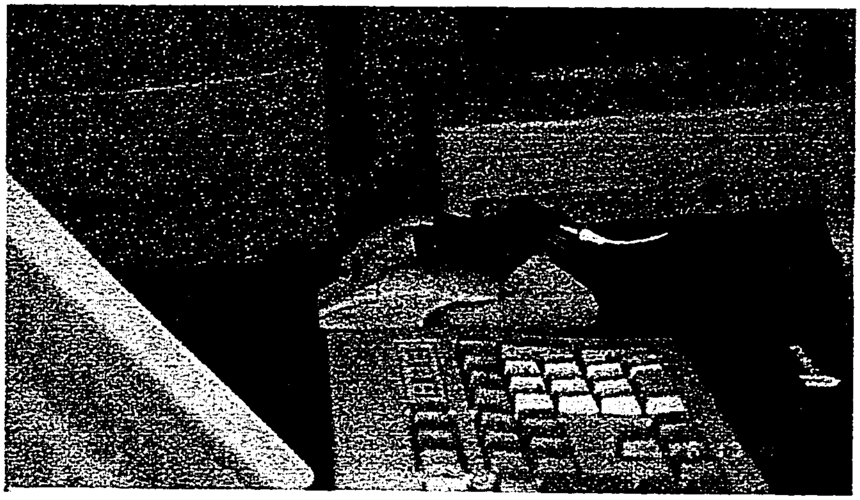

Figure 15. PC operator holding the hand off the mouse during computer mouse use resulting in increased wrist extension.

In summary, the use of chair armrests generally resulted in less time in non-neutral wrist extension postures. The use of chair armrests did not cause an increase in wrist extension when compared to not using chair armrests. These data did not support the concerns of ergonomists that using a chair armrest would increase non-neutral wrist postures based on the principle that stabilizing the forearm would encourage more motion at the wrist when compared to not using a chair armrest. The fact was that whether or not they were using a chair armrest, the PC operators supported the arm at the wrist on the mouse pad surface, resulting in increased wrist extension for both conditions.

It must be remembered that multiple factors had an effect on wrist extension in this study. Decreasing non-neutral wrist extension posture is not achieved solely by providing a chair armrest, as was seen in the data showing an overwhelmingly high degree of wrist extension in both armrest conditions. A chair armrest may assist in decreasing wrist extension for some PC operators, but it must be considered that the cause of increased wrist extension is multi-factorial. PC operators should be evaluated on an individual basis to determine the preferred armrest condition, while taking into consideration all other factors that can increase non-neutral wrist extension posture during computer mouse use.

Wrist Ulnar Deviation

The hypothesis stating that there would be no significant difference in wrist ulnar deviation posture was also not supported for wrist ulnar deviation for the four mouse tasks combined. Participants spent a greater amount of time in non-neutral ulnar deviation postures when using a chair without armrests versus using a chair with armrests. When analyzing the one single-mouse task, Vertical Drag, there was no significant difference in time spent in ulnar deviation postures >15°.

The interaction was significant for the analysis of four tasks combined. PC operators without armrest experience benefited from the use of chair armrests showing less time in non-neutral ulnar deviation postures with chair armrests. PC operators with experience did show similar (lower) percentages of time in non-neutral postures, independent of the armrest condition. This could suggest that the armrest users adapted the same technique to maneuver the mouse even when the armrests were removed.

When comparing the time spent in non-neutral postures for ulnar deviation with wrist extension, PC operators generally spent significantly less time in non-neutral postures for ulnar deviation. PC operators spent only 29% to 34% of the time in non-neutral posture > 15°. It would be interesting to determine if movement in this range category of ulnar deviation with a maximum range of 30° to 40° ulnar deviation at the wrist joint, may be considered a higher biomechanical risk when compared to moving 20° for wrist extension when maximum range is 60° to 70°. Working in this range of ulnar deviation with a higher ratio of movement (ulnar deviation ROM in the task: available ROM at the joint), in addition to the repetitive nature of the mouse task, could contribute to the risk by increasing stress to the tendons as identified by Armstrong and Chaffin (1979). This would be an interesting area of future study.

It was interesting to note that in tasks such as Solitaire and Scroller, that required horizontal motion of the cursor on the display screen, the majority of PC operators planted at the wrist and used radial deviation and ulnar deviation to maneuver the mouse with no shoulder motion. If shoulder motion was used in horizontal cursor tasks, shoulder abduction and adduction would be required. This was rarely observed during the computer mouse tasks. For detailed mouse work requiring horizontal cursor movement (i.e., point/click, highlighting text), planting and deviating at the wrist were the most common movements observed. Based on these observations, it should be considered that horizontal cursor movements may be more difficult and less natural when compared to shoulder flexion (i.e., forward reach) when performing vertical or diagonal cursor motions. This observation should be considered by ergonomists when instructing PC operators in technique to maneuver the computer mouse with the shoulder.

Operator Technique.

Analysis of operator technique showed that there was a strong tendency to work at the wrist and digits with the volar wrist in contact with the work surface, particularly when less range of cursor movement was required. Shoulder motion was minimal; however, shoulder motion was noted when increased cursor movement was required for the mouse task. When the wrist was planted and no shoulder motion was used, the wrist motion required to move the cursor across the screen was greater, sometimes resulting in picking up the mouse to increase excursion of the cursor. Some participants used forearm supination and pronation in combination with the wrist and digits; however, this hand motion appeared to be constrained for tasks requiring greater cursor movement.

Shoulder motion was present in a number of the tasks, particularly with those tasks that required greater cursor movement in the vertical and diagonal plane (working from upper to lower portions of the display screen). However, the quality of the motion when considering the amount of resistance to the arm movement, since the wrist was resting on the mouse surface with increased wrist extension was a concern for both armrest conditions.

It appeared that the overall ease of motion was greater without the armrest. If the movement was categorized as restricted without using the chair armrest, subjects had a tendency to hike the shoulder or use wrist and finger motions to gain the extra range. It appeared that the downward slope from the elbow to the volar wrist contributed to restricted motion by increasing the downward force into the mouse pad surface as opposed to a horizontal force which minimizes friction. When using a chair armrest, the same pattern was noted as most participants had a downward slope and the armrest interfered with smooth motion by providing a form of resistance. This resulted in greater wrist and finger motion. For two participants, the shoulder was used to maneuver the mouse with the forearm aligned on an even plane with the computer mouse. Greater forearm skin excursion allowing for movement of the volar forearm on the armrest, was a contributing factor to shoulder movement. Shoulder motion was also greater for these two participants since the wrist was not planted on the work surface, resulting in less resistance to shoulder motion.

As mentioned previously, there was a strong tendency for planting and working with the wrist and digits only for both conditions. Shoulder movement was used when increased excursion was required. This may be due to the functional demands of the mouse task. For example, Scroller, which required horizontal and diagonal movements to the lower and upper right half of the display screen, typically resulted in ulnar deviation for the lower portion and restricted shoulder motion with wrist and digit motion for the upper half due to the greater reach that was required. Typically, tasks requiring small range of vertical motion, such as Vertical Drag, used wrist extension and flexion combined with digit motion in a tenodesis-like motion (i.e., wrist extension and finger flexion and wrist flexion with finger extension with no shoulder motion). Large diagonal cursor motions, such as Corner Task which simulated closing programs in the upper right hand corner and moving to the Start icon in the lower left of the display screen, had the most observations using smooth shoulder motion. However, most of the shoulder movements requiring greater reach for the Start icon when using the right hand for the computer mouse were categorized as fair with limited and restricted shoulder motion combined with wrist motion.

It was also interesting to note the pattern of wrist motion when some of the operators planted at the wrist when increased cursor excursion was required. When moving to the upper right-hand corner of the display screen, the same tenodesis pattern was noted with the wrist moving toward flexion and the fingers extending as if to push the mouse away; on the downward and diagonal move to the Start icon, the PC operator would typically extend the wrist and flex the fingers while pinching the mouse. Forearm supination was also noted to increase cursor excursion in the diagonal direction when moving towards the left of the display screen. It appeared that only when the reach demands increased, did the shoulder become involved in maneuvering the mouse.

The options for minimizing the demands on the right arm of the PC operator during mouse use include (a) instructing the operator in a mouse technique to encourage greater shoulder motion and minimize non-neutral postures, (b) teaching keyboard shortcuts to perform mouse tasks, if available, and (c) considering software re-design of relocating commonly-used targets that result in greater non-neutral postures of the right arm (i.e., scrolling in the lower right-hand corner and closing programs in the upper right-hand corner). It is important to realize that the majority of PC operators have poor operator technique, particularly with planting at the wrist and overreaching for the mouse. Training the operator in keyboard shortcuts or a mouse technique that minimizes physical risk factors to the right arm can be beneficial. However, follow-through is a concern, as well as the ability to instruct the large population of PC operators. Developing software or creating a task that does not require moving the cursor to areas on the screen that demands non-neutral wrist motion for frequently-used commands has the potential to change the physical demands on PC operators without dependence changing the operator's technique. This would not reduce all physical risk factors, however, it could be one intervention that could minimize the risk that is inherent in the mouse task. It must also be realized that arm motions required to maneuver the mouse would be different for the right-handed and left-handed mouse user. This would be a recommended area of study for future investigators.

Points of Contact

As expected, points of contact on the right arm were greater when using the chair armrest. The proximal and middle forearm were the most common areas of contact with the armrest, as well as the volar wrist on the work surface. A point of contact at the elbow was observed for half of the participants. It was observed that the greater the forward reach, the more likely the elbow did not contact the armrest since the forearm was at a downward slope with the elbow higher than the armrest. This decreased the risk of elbow contact, however, it increased the uneven distribution of contact area at the elbow with the reach minimizing the distribution of even pressure, particularly at the mid-forearm. It was also noted that the slope of the armrest contributed to this pressure area. As mentioned previously, the slope of the armrest changes with the seat pan angle due to the chair design. If there is an upward slope of the armrest and greater forward reach is present, the distal end of the armrest appeared to produce a greater pressure point, mainly in the mid-forearm area with the downward slope of the forearm. This feature of chair armrests could contribute to greater risk (see Figure 16).

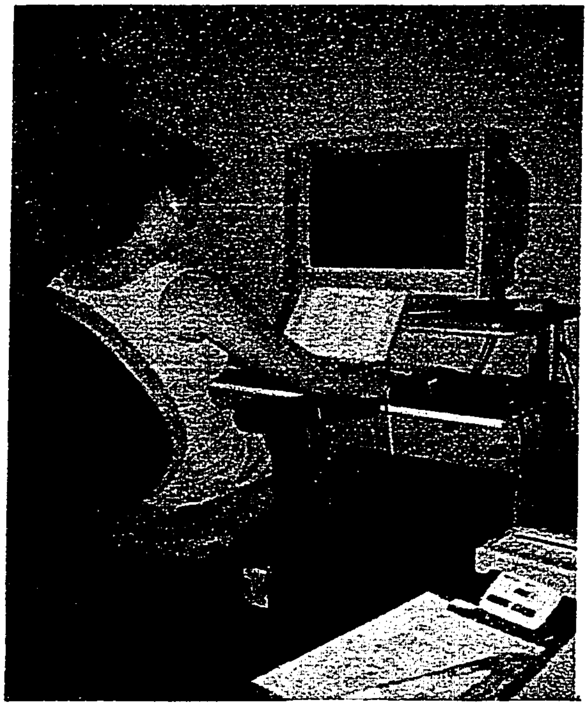

Figure 16. PC operator demonstrating point of contact at the mid-forearm with use of the chair armrest.

"Pivoting off the elbow" at the cubital tunnel area, which is a concern among ergonomists, was not observed for the majority of participants since the right arm was planted at the volar wrist, not allowing the elbow to "pivot" through shoulder rotation except for one participant. This may be more of an issue with using the keyboard since PC operators can typically rest the elbows on the armrests with shoulders abducted.

With the exception of two participants, the armrest did not prevent contact at the volar wrist as has been claimed by ergonomic equipment vendors. The majority of participants still planted at the volar wrist, despite proximal support. Whether the chair armrests actually helped decrease the amount of pressure at the volar wrist due to the proximal support is unknown. This would be an interesting area for future study. Analysis of the two participants who did not plant at the wrist when using the armrest was interesting. Both participants assumed a slightly reclined posture with the forearm in proper alignment with the chair armrest and mouse as claimed by the chair manufacturers, Body Bilt, Inc. However, there was more contact at the elbow (a risk factor implicated in CTDs), with proper alignment resulting from the shoulder and elbow being in a more neutral posture. Once the forward reach became greater and the wrist planted on the mouse pad surface, the alignment between the chair armrest and the forearm changed, resulting in a greater downward slope of the forearm and with less even distribution of points of contact, particularly at the mid-forearm.

Points of contact did change with time while using the mouse. Typically, there was a change in degree of forward reach resulting in greater contact at the distal forearm, along with the volar wrist. The mouse gradually moved toward the distal end of the mouse pad, resulting in a change of points of contact and increased reach of the upper extremity. This could be related to most tasks being positioned in the upper half of the screen. However, even when the custom mouse-based tasks were used that required moving the cursor to the lower portion of the screen, it was observed that participants did not bring the mouse closer to them.

Armrest adjustment had an effect on points of contact of the right arm. Some users did not use the angle adjustment with the chair armrest, resulting in greater pressure points, particularly at the radial aspect (thumb side) of the forearm when reaching for the mouse. Other participants did set up the armrests correctly by adjusting the angle and horizontal adjustment, allowing for an initial even distribution of points of contact. This even distribution would most often change throughout the tasks as the PC operator started to reach for the computer mouse.

Fatigue and Body Discomfort

Subjective ratings of fatigue of the right arm and body discomfort were significantly lower when using a chair armrest versus no chair armrest for all analyses. Even PC operators who did not use chair armrests strongly preferred the use of chair armrests. The fact that they do not currently use chair armrests in their work environment may not be due to preference, but due to lack of availability. This could explain the strong preference for chair armrest use. These results support the findings of Attwood (1986), Karlqvist et al. (1998), and Wells et al. (1997) that PC operators reported less discomfort when using proximal, external support while using the computer mouse.

Preference

The majority of the participants preferred using the chair armrest with the mouse (19 out of 20) despite their experience with using chair armrests. It is apparent that support of the right arm when working with the mouse was preferred. This is not surprising since PC operators were working with an extended, forward reach. This also supports the findings of Attwood (1986), Karlqvist et al. (1998), and Wells et al. (1997) that PC operators prefer the use of more proximal, external support while using the computer mouse.

Ratings on performance factors also showed a similar response, although not as significant as preference and comfort findings. The number of negative responses regarding speed and accuracy was minimal when evaluating subjective performance. Subjective assessment of chair armrest functionality also rated high. The majority of participants felt they could position the chair armrests in the preferred position. Only two participants felt they could not set the chair armrests low enough. However, it should be remembered that the majority of participants preferred to set the armrest higher than sitting elbow height. Subjective assessment of armrest interference showed that 17 participants perceived the armrest did not interfere with keying, however, some participants were observed to abduct their shoulders and place their elbows on the armrests while keying. From an ergonomics perspective, this would be considered a risk factor (see figure 17).

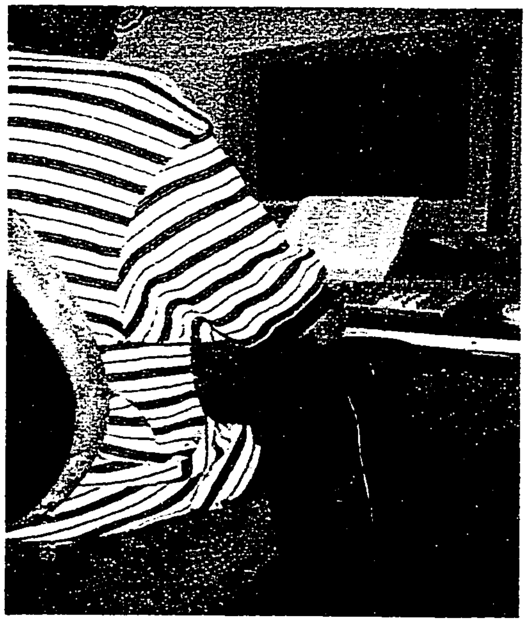

Figure 17. PC operator using chair armrest with points of contact at the elbow while keying. This operator stated that no interference was noted with chair armrests while using the keyboard.

This reinforces the point that the positioning of chair armrests must be addressed not only for use of during the computer mouse task, but for positioning during keyboard use as well. Evaluation by an ergonomist is recommended to evaluate interference with keyboard use and to aid in correct positioning of the chair armrest since it is apparent that some PC operators are not knowledgeable in correct armrest placement and areas to evaluate when working with the keyboard and mouse. This analysis can help determine whether using a chair armrest is preferred during computer use.

In summary, the use of chair armrests during computer mouse use does not seem to cause greater risk when evaluating wrist motion. The concern that chair armrests increases wrist motion and non-neutral wrist postures since the proximal forearm is supported when compared to not using chair armrests was not substantiated. The majority of PC operators are primarily moving from the wrist whether they are using an armrest or not. Shoulder movement without the chair armrest did appear slightly more fluid and did have a greater number of observations in the smooth shoulder category. However, the shoulder movement was primarily restricted with the wrist in non-neutral extension for both armrest conditions. Points of contact are greater with the chair armrest, indicating greater risk, primarily at the elbow. The majority of participants had contact at the volar wrist in both armrest conditions. Fatigue, body discomfort, and preference scores all indicated a positive effect for the use of chair armrests during mouse use. Refer to Table 5 for a summary of the advantages and disadvantages of chair armrests that was learned from this experiment and from other studies and observations made in the field.

Table 5. Summary of Advantages and Disadvantages of Using Chair Armrests During Computer Mouse Use With the Right Hand and Other Work Tasks.

Advantages	Disadvantages
Decreased non-neutral wrist extension posture	Point of contact on the elbow and forearm during mouse use
Decreased non-neutral wrist ulnar deviation posture	Point of contact in mid-forearm with reach during mouse use
Decreased fatigue	Potential increased pressure at mid-forearm with forward shoulder reach
Decreased body discomfort	
User preference	Increased point of contact at the volar wrist with forward shoulder reach
	Decreased quality of shoulder motion
	Point of contact at elbows with keying
Reduced static loading of shoulder muscles	Point of contact at elbows with leaning during work tasks
Reduced static loading of forearm muscles	Minimized close access to work surface

Note: The grey areas indicate areas that were evaluated or observed during the chair armrest experiment.

Delimitations of the Study

1. One standard computer mouse was used in the study. There are multiple types of mouse pointing devices of various shapes and sizes being used by PC operators that could have an effect on the dependent variables being studied.

2. One armrest style was used in the study. There are multiple styles of armrests with different adjustments currently used in the work environment.

3. The study included measurement of wrist range of motion only. Additional range of

motion measurements of the shoulder, elbow, and forearm, and trunk posture could contribute to the analyses of computer mouse use with and without chair armrests.

Limitations of the Study

1. The experiment was conducted in a laboratory setting. Although participants were asked to set up the workstation and chair to their preferred setting, the work environment and tools were not the same as the setup and tools used in their work setting.

2. This study defined the factor, Armrest Experience, as current armrest use in their work setting, however, the majority of armrest users had no training in how to use chair armrests or correct workstation setup. Although this was also true for armrest nonusers, the definition of an *armrest user* could be expanded for future studies.

3. The majority of mouse tasks in the study were intensive sessions of playing computer Solitaire throughout the testing period to allow for data acquisition during mouse use only. Minimal keyboard use was allowed (two 2-minute typing sessions). It is unknown whether the results would be different for intermittent computer mouse use (alternating between keyboard and mouse), which is common with the typical PC operator.

4. Participants were required to wear a glove on the right hand to obtain data for wrist ROM. Wearing a glove during computer mouse use was unfamiliar. Although the glove was lightweight and did not restrict ROM, application of the glove could result in a difference of sensation, resulting in a difference in body discomfort or fatigue ratings.

5. Participants had no formal ergonomics training. This could have an effect on workstation setup and technique since participants were allowed to set up the workstation.

Recommendations for Future Research

To further understand the effect of chair armrests during computer use, additional studies are recommended. A variation of this study could address many areas. These include:

1. Comparison of armrest use with various keyboard and input device layouts. Since the trend in the workplace is to recommend workstation setups that require less reach for the right computer mouse, analysis of wrist posture in the following input device layouts would be of interest: (a) short keyboard using the right mouse, (b) standard keyboard with left mouse use, and (c) standard keyboard with right mouse as was used in this study. Setup of the workstation and armrests by the researcher according to ergonomic recommendations should be considered.

2. A study determining the optimal chair armrest height for keyboard and computer mouse work is recommended. The effect on the shoulder and wrist posture, trunk posture, armrest interference while keying, and leaning on the chair armrest should be evaluated.

3. Comparison of styles of operator technique during mouse use (i.e., wrist planted on the work surface versus moving through the shoulder). Analysis of wrist and forearm posture, as well as EMG activity of the shoulder, forearm, and wrist muscles would be beneficial.

4. Comprehensive field study analyzing the sitting postures and right arm posture over a period of time in the PC operator's work setting would be beneficial. The study could also include looking at the other factors related to mouse use such as (a) body posture,

(b) armrest interference with access to the writing work surface, (c) how often operators lean on chair armrests for various work tasks, and (d) work at the computer or during conversation. The frequency of propping elbows on the armrests while using the keyboard could also be evaluated. This baseline measurement could assist researchers, ergonomists, and chair manufacturers in determining appropriate products and recommendations for the PC operator.

CONCLUSION

The use of chair armrests by PC operators has been increasing over the last few years. Yet, there is little research, let alone established guidelines, to suggest their benefits (or costs) or to specify the optimal way to setup and interact with armrests. There has been concern expressed by the ergonomics community that armrests could increase non-neutral wrist postures since the upper arm and forearm are supported on the armrest, theoretically requiring more wrist motion. However, no studies that specifically address the issue of wrist posture while using the chair armrest have been published to date.

The purpose of this study was to determine the effect of chair armrests on wrist posture, operator technique, and points of contact in the context of mouse-based computer activity. Results showed that use of chair armrests generally resulted in less time in non-neutral wrist postures (> 15°) for wrist extension and ulnar deviation, and that participants rated the use of armrests as more comfortable and less fatiguing. However, the points of contact and shoulder motion afforded by the armrest condition indicate a possible increased risk. Surprisingly, no benefit of decreasing the point of contact at the volar wrist was found, as would be expected when providing a chair armrest with proximal forearm support.

The results also showed that, for ulnar deviation, PC operators without prior armrest experience benefited from the use of chair armrests, whereas users with prior armrest experience showed similar (lower) postural deviations with or without the armrests. This suggests that armrest users have adapted their posture so that they show the benefits of the armrest even when they are not using it.

It is concluded that chair armrests have both advantages and disadvantages and suggest that further research must be conducted to understand the full impact of chair armrests on the PC operator in the work environment. Further, it is recommended that PC operators be evaluated individually to determine the optimal setup for their work environment, since many factors can contribute to CTD risk.

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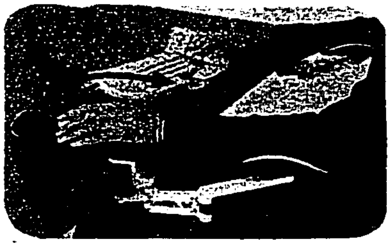
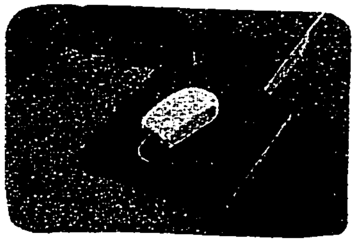
Appendix A

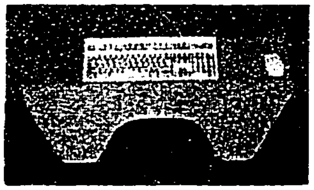
Forearm Supports for Computer Mouse Use



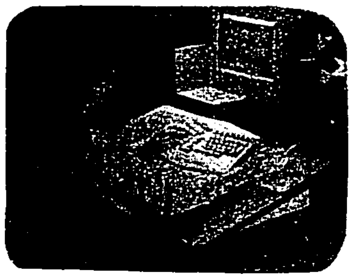
ErgoRest Articulating Arm Support with Mouse Pad



Mouse Arm



Morency Rest with Double Mouse Rest



Comfort Board

Illustration of available forearm supports for computer mouse use offered by AliMed Products, Dedham, MA. Reprinted with permission.

Appendix B

Guidelines for Chair Armrests in ANSI 100-1988

ANSI/HFS 100-1988, American National Standard for the Human Factors Engineering of the Visual Display Terminal Workstations.

8.7.7 Armrests

General Solution:

The minimum inside distance between armrests shall be equal to at least the clothed hip breadth of the user.

Specific Solution:

When provided, the inside distance between the armrests shall be at least 46.2 cm. (18.2 inches), the clothed hip breadth of the 95th percentile female.

Appendix C

Product Claims by BodyBilt Seating, Inc.

Armrest Height & Angle Adjustment

Posture Guidelines

Your arms should be fully supported by the chair's arm pads (i.e. not dangline or supporting their own weight), without being pushed upward.

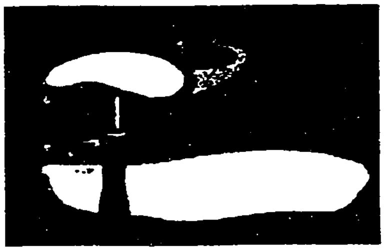
Proper adjustment will help alleviate neck and shoulder strain and headaches, and can considerably lessen the risk of Carpal Tunnel Syndrome by providing proper alignment of the hand, wrist and forearm along the same plane.

How To Adjust:

Raise the cam lever located on the outside edge of the arm bracket.

While the lever is in the raised position, you may adjust the arm to whatever height and angle best supports the weight of your arms.

To lock the pad into position, flip the lever back down.



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Appendix D

Screening Questionnaire

Please fill out the following information. Your responses will be confidential.
Name:____________________________ Age:__________ Sex:__________
Occupation:____
Height:____________ Weight:___________

1. Have you attended an ergonomic training class? ___No ___Yes
   If yes, what year?_________

2. Number of hours per day on computer:___________

3. Years of experience using a PC computer________

4. What type of device are you currently using at work?
   _____Mouse ____Trackball ____ Other:_________________________

5. What hand do you use for mousing? ___Right ___Left
   ___ Able to mouse with both hands

6. Do you use a wrist support with the mouse? ____Yes ____No
   wrist support for the keyboard? ____Yes ____No

7. Check if you have pain in the following areas:

	If yes, please explain
______ Neck	____
______ Shoulder	____
______ Elbow	____
______ Forearm	____
______ Wrist/Fingers	____

8. Have you been treated by a physician for any neck or arm problems? ___Yes ___ No

9. Do you experience any discomfort with mouse use? ____Yes ____No

10. Do you use a chair armrest during mouse use? ____Yes ____No

11. Do you know how to play Solitaire on the computer? ____Yes ____No

Appendix E

Participant Consent Form

SJSU SAN JOSE STATE UNIVERSITY

College of Engineering • *Office of the Dean* • One Washington Square • San José, California 95192-0080 • 408/924-3800

Agreement to Participate in Research

Responsible Investigator: Kathy Appenrodt OTR,CHT
Title of Protocol: Evaluation of Chair Armrests while using the PC Computer

I understand that:

- I have been asked to participate in a research study that will investigate the use of chair armrests while using a PC computer.
- I will be asked to come to the testing lab at Interface Analysis Associates, 1135 S. DeAnza Blvd, in San Jose at a designated time. The testing session will last for 2 hours.
- I will be asked to play the computer game, Solitaire, for a total of one hour. The session will be videorecorded. I will be asked to fill out written evaluation tools that will take approximately 15 minutes.
- The criteria for this study is that subjects will have no recent history of upper extremity injury.
- The possible risks of this study are no greater or different than those which I might encounter in routine everyday life.
- There are no discernible benefits to be received from participating in this research study.
- The results of this study may be published but no information will be used that could expose my identity. Any information that can be identified by me will remain confidential and will be disclosed only with my permission or as required by law.
- I will be paid $10.00/hour for participation in this study.
- Any questions regarding this research project may be addressed to the investigator, Kathy Appenrodt (408) 684-1934. Complaints about the research project may be directed to the chairperson of the SJSU Industrial Ergonomics Department, Lou Freund (408) 924-3890. Questions or complaints about my rights or research-related injury may be presented to Serena Stanford, Ph.D., Associate Academic Vice President for Graduate Studies and Research at (408) 924-2480.

- I understand that no services of any kind, to which I am otherwise entitled, will be lost or jeopardized, if I choose not to participate in the study.
- I understand that my consent is given voluntarily. I may refuse to participate in the study or any part of the study. If I decide to participate in the study, I will be free to withdraw at any time without prejudice to my relations with San Jose State University or any other participating institution.
- I understand that the signature on this document indicates agreement to participate in this study.

______________________________ ________________

Subject's Signature Date

______________________________ ________________

Investigator's Signature Date

Appendix F

Static Measurements Taken During the Chair Armrest Experiment

Participant:______

Static Measurements

Hand Length	______	
Forearm Length	______	
Elbow to Elbow Breadth	______	
Shoulder to Shoulder Breadth	______	

	Condition 1		Condition 2
Seated Elbow Height (arms 90°)			_____
Seated Elbow Height (hand on mouse)	_____		_____
Chair Armrest Height:	_____		
Armrest Angle	_____		
Keyboard Height	_____	or	_____

Start: ___With Armrest ___Without Armrest

Session 1: Resting Position (20 sec.)	Session 9:
Session 2: Solitaire	Session 10
Session 3: Point & Click and Corner	Session 11:
Session 4: Solitaire	Session 12:
Session 5: Dragster	Session 13:
Session 6: Scroller Coaster	Session 14:
Session 7: Solitaire	Session 15:
Session 8: Vertical Drag	Session 16:

Repeat same sessions with alternate condition (sessions 9-16)

Appendix G

Pretest Measurement of Right Arm Fatigue

Participant:_______
Pretest:___1 ___2

Circle the level of **arm fatigue** you are currently experiencing in your right arm:

No Fatigue	Slightly Fatigued	Moderately Fatigued	Very Fatigued	Severely Fatigued

Appendix H

Posttest Measurement of Arm Fatigue – Condition 1

Participant _______
Condition 1

Circle one that describes the level of **arm fatigue** you experienced when using the chair armrest with the computer mouse:

No Fatigue	Slightly Fatigued	Moderately Fatigued	Very Fatigued	Severely Fatigued

Appendix I

Posttest Measurement of Arm Fatigue – Condition 2

Participant _______
Condition 2

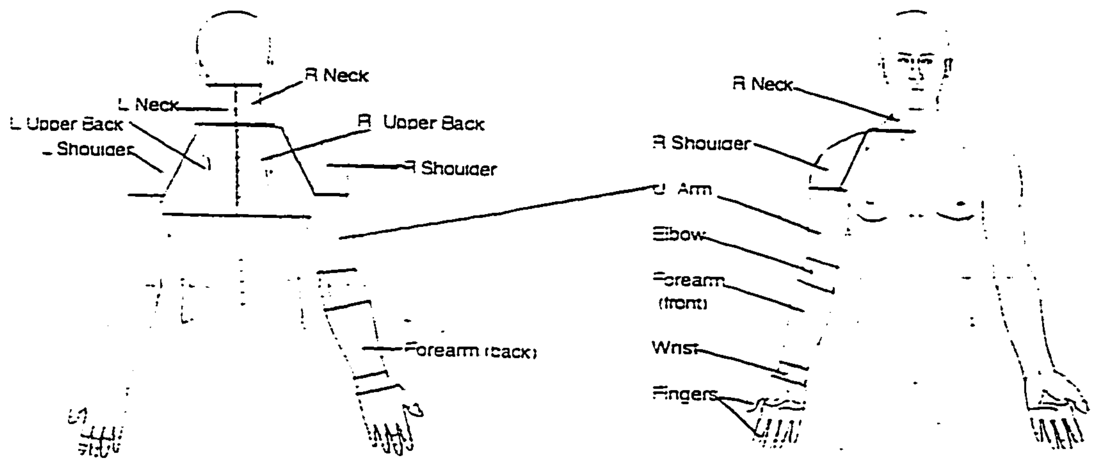
Circle one that describes the level of **arm fatigue** you experienced when using the computer mouse:

No Fatigue	Slightly Fatigued	Moderately Fatigued	Very Fatigued	Severely Fatigued

Appendix J

Body Discomfort Rating - Male

Rate the level of comfort you are experiencing at this time for each body part.
0 = no discomfort; 4 = severe discomfort



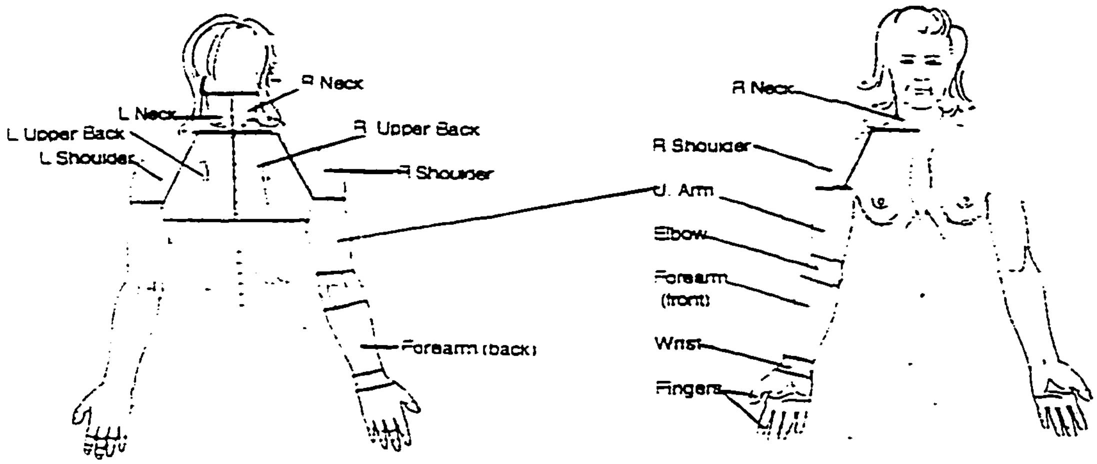
0 = No discomfort
1 = Mild discomfort
2 = Moderate discomfort
3 = Moderate-Severe discomfort
4 = Severe discomfort

		Rating			Rating
Right	Neck	____	**Left**	Neck	____
	Upper Back	____		Upper Back	____
	Shoulder	____		Shoulder	____
	Upper arm	____			
	Elbow	____			
	Forearm (front side)	____			
	Forearm (back side)	____			
	Wrist	____			
	Fingers	____			

Appendix K

Body Discomfort Rating - Female

Rate the level of comfort you are experiencing at this time for each body part.
0 = no discomfort; 4 = severe discomfort



0 = No discomfort
1 = Mild discomfort
2 = Moderate discomfort
3 = Moderate-Severe discomfort
4 = Severe discomfort

		Rating			Rating
Right	Neck	____	**Left**	Neck	____
	Upper Back	____		Upper Back	____
	Shoulder	____		Shoulder	____
	Upper arm	____			
	Elbow	____			
	Forearm (front side)	____			
	Forearm (back side)	____			
	Wrist	____			
	Fingers	____			

Appendix L

Post-Evaluation - Part One

Choose any of the following statements that best describe how you feel about **chair armrests when using the computer mouse:**

Check one: COMFORT

☐ I feel chairs <u>with</u> armrests are more comfortable while working with the computer mouse.
☐ I feel chairs <u>without</u> armrests are more comfortable when working with the computer mouse.
☐ I feel no difference in comfort when working with the computer mouse <u>with or without</u> chair armrests.

Check one: SPEED

☐ I feel I work faster when using the mouse in a chair <u>without</u> armrests.
☐ I feel I work faster when using the mouse in a chair <u>with</u> armrests.
☐ I feel no difference in how fast I work when using the mouse <u>with or without</u> chair armrests.

Check one: ACCURACY

☐ I feel I am more accurate with a computer mouse in a chair <u>with</u> armrests.
☐ I feel that I am more accurate with a computer mouse when using a chair <u>without</u> armrests.
☐ I feel no difference in my accuracy when using a mouse <u>with or without</u> chair armrests.

Check one: ARM RELAXATION

☐ I feel my right arm is more relaxed when I use a chair <u>with</u> an armrest while using the mouse.
☐ I feel my right arm is more relaxed when I use a chair <u>without</u> an armrest while using the mouse.
☐ I feel no difference in how relaxed my arm is <u>with or without</u> using a chair armrest while using the mouse.

Check one: POSITIONING OF CHAIR ARMREST

☐ <u>I do not feel I could</u> position the chair armrest in the position I wanted when using the mouse.
☐ <u>I feel I could</u> position the chair armrest in the position I wanted when using the mouse.
☐ I did not notice if I could position the chair armrest in the position I wanted when using the computer mouse.

Check one: ARM IRRITATION AND CHAIR ARMRESTS

☐ I feel that the points where my arm touched the chair armrests <u>were irritating</u> on my right arm when I used the computer mouse.
☐ I feel that the points where my arm touched the chair armrests <u>were not irritating</u> on my right arm when using the computer mouse.
☐ I did not notice whether the points where my arm touched the chair armrest were irritating on my arm or not when using the computer mouse.

Check one: ARMREST INTERFERENCE WITH KEYING

☐ I feel that the chair armrests were in the way when I was using the keyboard.
☐ I feel that the chair armrests did not get in the way when I was using the keyboard.
☐ I did not notice if the chair armrests got in the way when I used the keyboard.

Appendix M

Post-Evaluation - Part Two

Participant ______

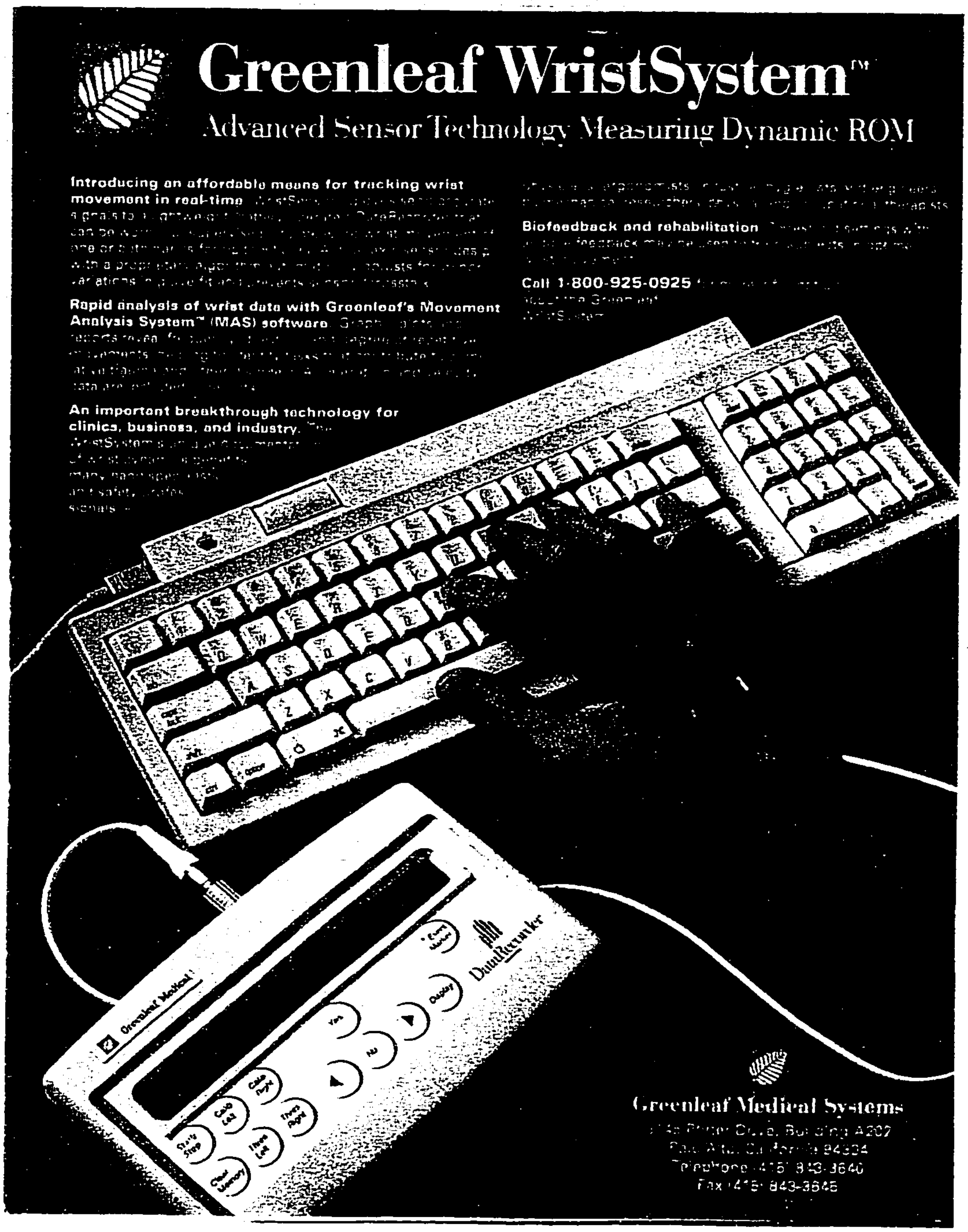
Which chair setup did you prefer when using the computer mouse?

____Chair with armrests ____Chair without armrests ____No Preference

Why?____
____
____
____
____
____
____
____

Appendix N

Greenleaf WristSystem™



Appendix O

Logitech First Mouse

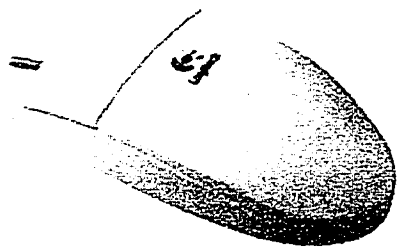


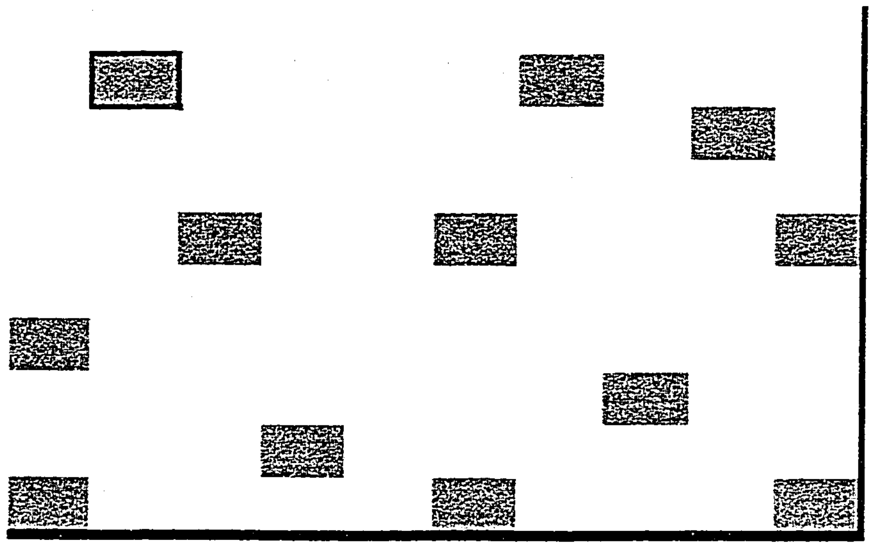
Illustration of Logitech First Mouse used in the chair armrest experiment.

Neutral Posture Chair

Model # 5500 is the medium-sized ideal office chair. The medium-air backrest and moderate contoured seat pan combine to provide optimal seated support for all types of work. This chair also features the three-way adjustable armrests. Air lumbar is standard.

Appendix Q

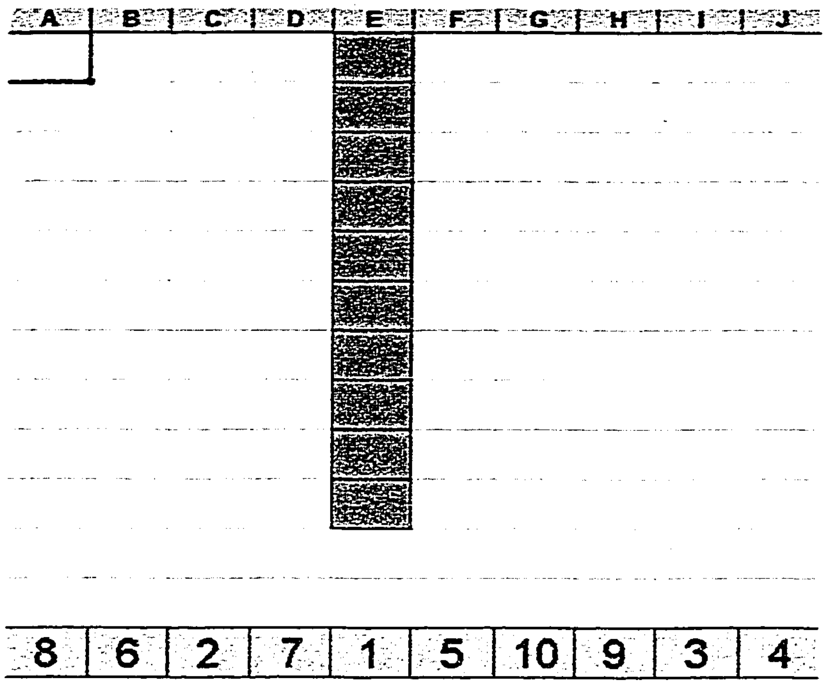
Computer Mouse Task - Clicker



Verbal Directions: "Point and click on each of the purple boxes and enter the number 1 with your left hand."

Appendix R

Computer Mouse Task – Dragster



Verbal Directions: "Click on the #1 box, move the cursor to the frame of the box, and it will turn into an arrow. Click and drag the #1 box to the top of the red column. Repeat this with the other numbers in numerical order."

Appendix S

Computer Mouse Task- Scroller

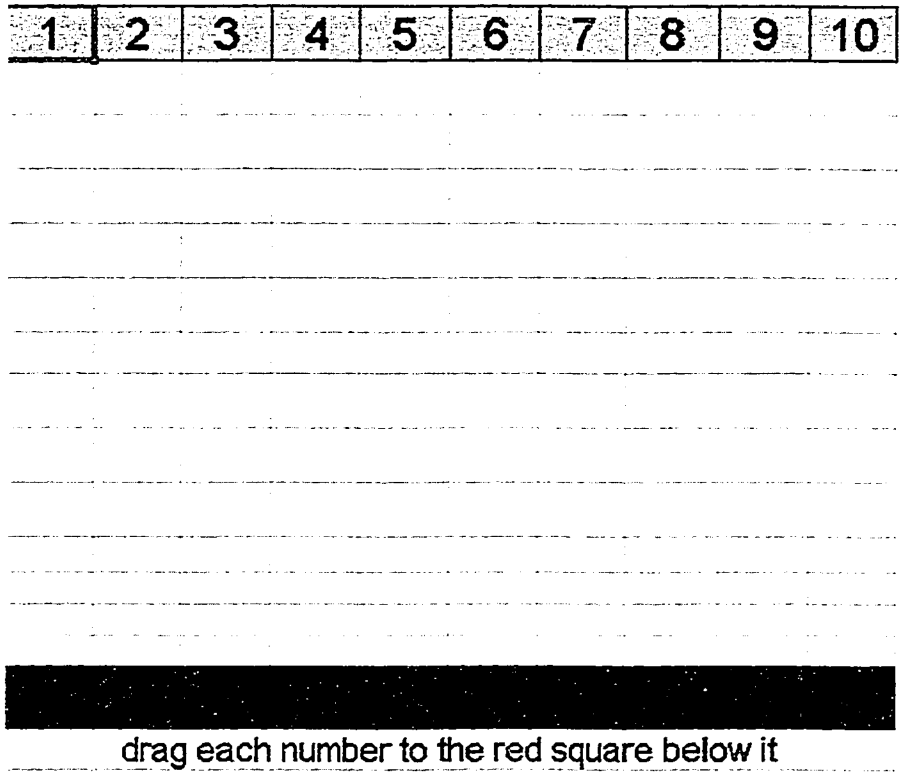
A	A	8	11	8	8	11	42	19	24
A	A	12	17	12	12	17	4	5	4
8	11	8	25	18	18	25	8	11	8
12	17	12	35	24	24	35	12	17	12
18	25	18	0	-13	-13	0	18	25	18
24	35	24	53	36	36	53	24	35	24
30	0	-13	11	8	12	61	30	0	-13
36	53	36	17	12	18	66	36	53	36
8	11	8	25	18	24	70	42	61	42
12	17	12	35	24	-13	102	A	A	54
18	25	18	0	-13	36	30	A	A	72

CLICKER / DRAGSTER \ SCROLLER COSTER / VERTICAL DOWNDRAGSTER / Sheet

Verbal Directions: “Scroll to find the blocks of letter *A*, click and drag to highlight the block of letters, and delete them.”

Appendix T

Computer Mouse Task - Vertical Drag



Verbal Directions: "Drag each number to the red square below it."

Appendix U

Testing Procedure

Testing Procedure for With Armrest Condition First (condition one)
Italics = Verbal directions

1. Welcome and thank you for participating.

2. Describe study: *This is a study that will examine the use of chair armrests during computer use. It will take approximately 2 hours. I will be putting a glove on your hand that you will keep on while you are working. The task involves working at the computer for 25 minutes, then you will fill out some forms and take a 15 - minute break. After the break, you will be asked to repeat the same procedure. I will be videotaping and moving between the two rooms throughout the testing sessions.*

3. Fit WristSystem glove.

4. Participant reads and signs the consent form.
Researcher inserts sensors into glove and turns on datarecorder (no data collection).

5. Take anthropometric measurements including:
A. Hand length
B. Forearm length
C. Elbow-to-elbow breadth
D. Shoulder-to shoulder breadth

6. Mark subject's proximal forearm with nonpermanent ink marker. Middle and distal forearm and hand are marked with tape on glove after glove is applied.
Place fluorescent dots on elbow and shoulder.

7. Give the questionnaires with the following instructions:
(a) Premeasurement of Arm Fatigue: *Please fill out this form that best describes your level of right arm fatigue at this time.*
(b) Body Discomfort: *Please fill out this form that best describes the level of discomfort you are feeling in each of the body parts listed at this time.*
Clarify body parts on form.

8. Instruct participant to adjust workstation.
You will be working at this workstation to perform computer tasks with both the keyboard and mouse. You are allowed to adjust the workstation and chair to any position you prefer. When you are ready, you will be able to work with the set up for 5 minutes before

starting the testing session. I will now explain to you how to make the chair and workstation adjustments. If you have any questions, I can answer questions that are only related to how to mechanically adjust the chair or the workstation. I am not allowed to answer any questions on what position to place the workstation and chair in.

The chair adjustments include a back angle adjustment (demonstrate), height adjustment (demonstrate), and seat tilt adjustment (demonstrate). The chair back can be raised and lowered here. Adjust the chair so it feels comfortable to you now. (WAIT FOR ADJUSTMENTS.)

The armrests can adjust either up or down (demonstrate), in and out (demonstrate), or swivel so there is a longer armrest and a short side of the armrest (demonstrate). Adjust the chair armrests so they will be comfortable for you while working at the computer.

The workstation has two adjustments- the monitor portion which can be adjusted with this handle and the keyboard tray portion which can adjust in height and depth with the pedal on the floor. You can make the adjustments now. (WAIT FOR ADJUSTMENTS)

9. Before we begin, I would like to review the computer tasks with you. Review Solitaire game, Corner Tasks Clicker, Dragster, and Scroller Coaster.

10. Calibrate Greenleaf WristSystem™:

(a) Glove and liner on hand and align
(b) Mark middle and distal forearm with paper tape on glove.
(c) Place in wrist calibration device and strap in.
(d) Press "Calib right"
(e) Flex/Ext - Check for "pure movement"
(f) Uln/Rad.Dev.- check for "pure movement"
(g) Verify ranges with observation and manual goniometer. Press DISPLAY button.

Go back to workstation:
11. Now we can start the trial period. This period is to make sure you have the workstation set up as you want it. Feel free to make adjustments during this time. I can assist you, if needed. You will not be able to make adjustments after this trial period. Open up Word by clicking on Programs.

Start the 5-minute trial that includes the following tasks:
- Start off with a one-minute word processing task.
- Four minutes of Solitaire.

You have 4 minutes to play Solitaire and make sure that your workstation is set up as you want it.

Check camera angles.

12. *Place your hand on the mouse.*
(Right edge of mouse is 2" from the keyboard and centered on the mouse pad.)
Take the following measurements:
(a) Seated elbow height while on mouse
(b) Mouse pad height (keyboard + mouse pad)
(c) Chair armrest height

13. *You will now be asked to play the Solitaire game and other computer tasks for 25 minutes. Please follow my verbal directions throughout the testing session. Work at your own pace.*

14. Computer Task:

(a) Center yourself on the keyboard with your hands on the home row. Paragraph type for 2 minutes (to position in front of keyboard). Turn on videorecorder.

(b) Now, rest your hand on the mouse for 20 seconds.
Turn on the WristSystem datarecorder and take static measurements of the wrist placed on the mouse (mid-pad) for 20 seconds.
Turn off the datarecorder to create one session. Take 35 mm pictures.

(c) Solitaire - 5 minutes with intermittent point and click
Open up Solitaire. You can play for the next 5 minutes.
(Take pictures and identify points of contact.)

(d) After 5 minutes, start task requiring point and click.
Turn on WristSystem datarecorder.
Now, I will ask you to do some certain tasks using the mouse
point and click on 10 of the cards.
Event Marker
Click on the minimize button (left dash button).
Click on Start
Click on the minimize button.
Click on Start.
Click on the minimize button.
Click on Start.
(Turn off Wristsytem datarecorder.)

(e) (Turn on the WristSystem datarecorder.)
Now, continue to play Solitiare for 2 minutes.

(After 2 minutes, turn off the WristSystem datarecorder)

(f) *Now, open up Word :*
Now continue typing the document. If you make a mistake, you can correct it.
(Participant types for 2 minutes.)

(g) Turn on WristSystem datarecorder.
Now, open Kathy's tasks and go down to just above the task bar area and click on the folder "Clicker." Point and click on each of the purple boxes and enter the #1 with your left hand.
Event Marker
Open up "Dragster. Click on the #1 box, move the cursor to the frame of the #1 box, and it will turn into an arrow. Click and drag the #1 box to the top of the red column. Repeat with the other numbered boxes in numerical order.
Turn off WristSystem datarecorder.

(h) Turn on WristSystem datarecorder.
Open up Scroller. Scroll to find the blocks of the letter A, click and drag to highlight the block of letters and delete them.
Turn off the WristSystem datarecorder.

(i) *Exit the program under the File menu. Choose "No Changes."*
You can continue to play Solitaire for the next 8 minutes.
Turn on the WristSystem datarecorder.
Click on Solitaire.
Maximize the screen in the upper right- hand corner.
Measure elbow extension and identify points of contact 3 minutes prior to completion of Solitaire session.
(After 8 minutes, turn off WristSystem datarecorder.)

(Added to procedure for the last 15 subjects.)
(j) (Turn on the WristSystem datarecorder).
Open up Vertical Drag. Drag each number to the square below it in numerical order."
(Turn off the WristSystem datarecorder)

15. At the end of the testing session, give the following assessments:
(a) Body Discomfort: *Please fill out the discomfort rating form that best describes the level of discomfort you are feeling in each of the body parts listed.*
(c) Arm Fatigue: *Please fill out the fatigue rating form that best describes your level of right arm fatigue at this time.*

15-Minute Break
Researcher to do the following during the break:

(a) Turn off the videotape
(b) Put on chair armrests (or take off chair armrests).

16. Now, we will begin the second half of the study. Before we start, please fill out the following forms.
(a) Premeasurement of Arm Fatigue
(b) Body Discomfort

17. Sit at your workstation again.
No Armrest Condition: You will notice that your chair armrests have been removed from the chair. You can now start the 5-minute trial period to get used to this new setup. You are not allowed to make any changes to the workstation or chair at this time.

Continue with Steps 11 through 15.

18. Please complete the following two questionnaires. Take your time to give feedback on the questions asked. If you have any questions, please ask.

19. Thank subject for participating.

Note: If the testing session begins with the participant using no chair armrests (condition 2), the following instructions will be given after the break.

Armrest Condition: You will notice that you now have chair armrests on your chair. The armrests can adjust either up or down (demonstrate), in and out (demonstrate), or swivel so there is a longer armrest and a short side of the armrest (demonstrate). Adjust the chair armrests so they will be comfortable for you while working at the computer.
(WAIT FOR ADJUSTMENTS)
You can practice for 5 minutes on the computer again to get used to the new setup. You can only make adjustments to the chair armrests at this time.
Do not make other adjustments to your chair or the workstation.

Appendix V

Videoanalysis/Observation Data Sheet

Participant :____ Condition ___1 ___2

CONTACT AREA / MOTION ANALYSIS
(Video Analysis)

Points of Contact:

Initial	End (last 3 minutes)	
____	____	Elbow
____	____	Proximal Forearm
____	____	Mid forearm
____	____	Distal forearm:___Mouse pad ___ Armrest
____	____	Volar Wrist
____	____	Mouse on Mouse Pad (from distal edge of mouse pad)

Operator Technique: Dynamic Motion Analysis

Pointing Task	Smooth Shoulder Motion	Restricted Shoulder Motion	0 to Minimal Shoulder Motion (Wrist / Fingers)
Scroller			
Vertical Drag			
Corner Tasks			

GLOSSARY

Acromion Process. The acromion process is located on the spine of the scapula. It attaches to the clavicle. It can be palpated on the outer edge of the shoulder joint. It is commonly used as a landmark for anthropometric measurements.

Carpal Tunnel Syndrome. Compression of the median nerve within the carpal canal. Diagnostic findings include sensory disturbance in the median nerve distribution including the volar thumb, index, middle, and half of the ring finger. As symptoms progress, the motor branch of the median nerve can become involved, resulting in weakening of the thenar muscles of the thumb.

Cubital Tunnel Syndrome. Compression of the ulnar nerve at the elbow. The ulnar nerve lies in the cubital tunnel and is vulnerable to compression when both the olecranon process and medial epicondyle apply pressure to a hard surface. Signs of cubital tunnel syndrome include pain in the forearm and elbow and sensory disturbance in half the ring and the little finger.

Cumulative Trauma Disorder (CTD). Disorder of the soft tissues due to repeated, forceful exertions and/or awkward non-neutral postures of the body over time. CTDs have also been called repetitive strain injuries (RSIs) and Musculoskeletal Disorders (MSDs).

Extensor Carpi Ulnaris. Functions as an ulnar deviator of the wrist and wrist extensor with the forearm supinated. It assists in stabilization of the wrist during gripping activities. It originates at the proximal portion of the ulna and inserts at the base of the 5th metacarpal bone (Brand & Hollister, 1993; Brunnstrom, 1992).

Extensor Forearm Musculature. Group of extensor muscles that originate in the forearm and insert in the wrist and hand. These include the extensor carpi radialis brevis (ECRB), extensor carpi radialis longus (ECRL), extensor carpi ulnaris (ECU), and the extensor digitorum communis (EDC).

First Dorsal Interosseous. Functions as an abductor of the index finger and plays a major contribution in key pinch activities (thumb opposing the radial side of the index finger). It originates at the radial aspect of the index finger metacarpal and inserts at the base of the proximal phalanx.

Flexor Digitorum Superficialis (FDS). Finger flexor muscles that flex the proximal interphalangeal (PIP) and metacarpophalangeal (MP) joints. The FDS originates in the forearm at the medial epicondyle and inserts at the base of the middle phalanx at the PIP joint. Muscle bellies of the four fingers are separate, allowing for isolated motion.

Infraspinatus. Functions as an external rotator of the shoulder joint. The muscle originates at the lateral border of the scapula and infraspinous fossa and inserts at the head of the humerus.

Intracarpal Pressure. Intracarpal pressure refers to the amount of pressure within the carpal canal at the wrist. Pressures exceeding certain levels over a period of time can result in nerve dysfunction.

Lateral Epicondilitis. Inflammation of the common extensor tendon of the forearm musculature. Also known as "tennis elbow," lateral epicondilitis results from chronic overuse of the muscles originating at the lateral epicondyle of the humerus. Greater involvement is typically present at the origin of the ECRB (Powell & Burke, 1991)

Maximum Voluntary Contraction (MVC). MVC is the maximum voluntary contraction that a muscle is able to generate (Kiser, 1987). It is commonly used as a baseline measurement in surface electromyography when determining the muscular workload of physical tasks in the ergonomics field.

Myofascial Syndrome. As defined by Janet Travell & D. Simons (1983), myofascial pain or trigger point is a "hyperirritable spot, usually within a taut band of skeletal muscle that is painful on compression. It can give rise to characteristically referred pain, tenderness and autonomic phenomena" (p.3).

Olecranon Process. The olecranon process is the tip of the elbow located at the proximal end of the ulna. It is prominent at the bottom of the elbow and is commonly used as a landmark in anthropometric measurements.

Shoulder External Rotation. A transverse rotation of the humerus toward the anterior side of the body (Brunnstom, 1972). Average range of motion is 0° to 80° (Kapandji, 1982).

Shoulder Internal Rotation. A transverse rotation of the humerus toward the posterior side of the body. Average range of motion is 110° when the hand is placed behind the trunk with the elbow flexed to 90° (Kapandji, 1982).

Surface Electromyography (EMG). Measures the level of electrical activity of skeletal muscle. EMG identifies both the number of motor units being recruited and the frequency motor units fire. EMG is used to assess the activity level of several motor units of one muscle and muscular fatigue (Sommerich, McGlothin, & Marras, 1993).

Tendinitis. Inflammation of the tendon resulting from microtears from high forces and repetition at lower forces (Ranney, 1993). Clinical findings typically include soreness of the muscle-tendon unit with increased pain when resistance and passive stretch are applied to the muscle.

Tenodesis Motion. Pattern of motion resulting from tension of the wrist and finger flexors of the hand with active or passive wrist extension. With wrist extension, the fingers will flex; with wrist flexion, the fingers will extend. Tenodesis-like motion mimics the tenodesis pattern of motion.

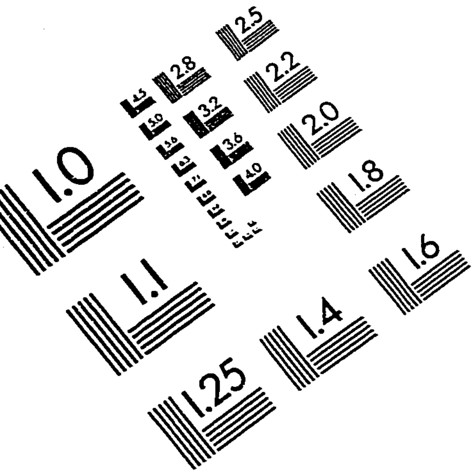
Thoracic Outlet Syndrome (TOS). TOS is a compression of the brachial plexus as it passes through the neck and cervical rib region. Common sites of compression of the neurovascular structures of the brachial plexus include the (a) scalene space, (b) costoclavicular space, and (c) the subpectoral area. Symptoms are typically vague and diffuse making diagnosis difficult. However, common symptoms include pain, numbness, tingling, and paresthesias (Toby & Koman, 1989).

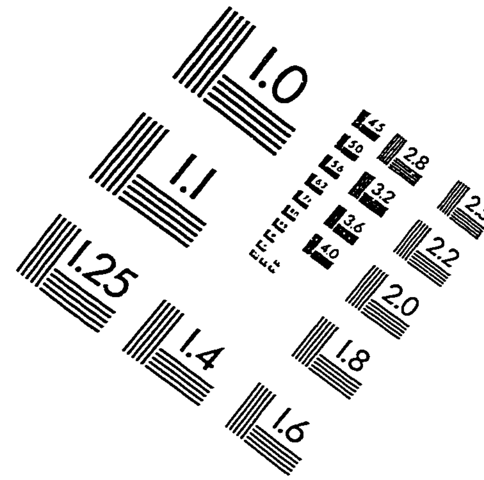
Trapezius. A large muscle located in the neck and upper back. There are three portions of the muscle with each having a specific function. Muscle functions include scapula retraction and upward rotation, shoulder abduction, elevation, and depression. It is commonly used in EMG studies due to its superficial location and its function as a scapula elevator, a common muscle used.

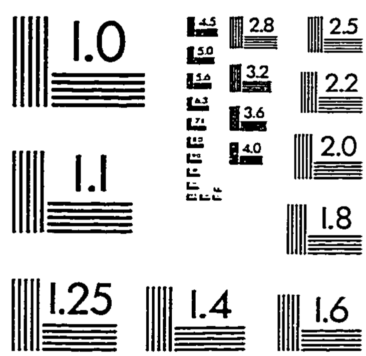
Ulnar Tunnel Syndrome. Compression of the ulnar nerve at the wrist due to compression, repetitive occupational trauma, fractures, arthritis, and/or vascular pathology of the ulnar artery located within the ulnar tunnel (Szabo, 1989). Clinical findings can include sensory symptoms of the ring finger and little finger and/or motor nerve symptoms including motor weakness of the intrinsic muscles of the hand (interossei, hypothenar muscles, and adductor pollicis).

Volar Surface of the Wrist. This surface of the wrist is also known as the anterior or palmar surface of the wrist. It is located at the base of the palm and is commonly referred to as the carpal tunnel area in the ergonomics literature.

IMAGE EVALUATION TEST TARGET (QA-3)

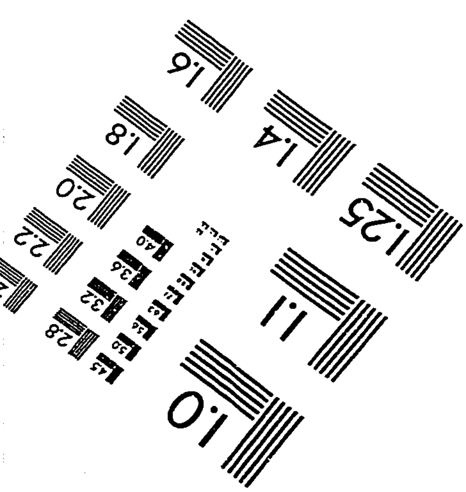


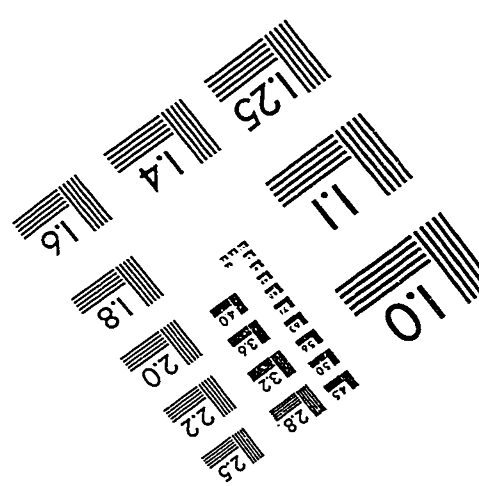




150mm

6″





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